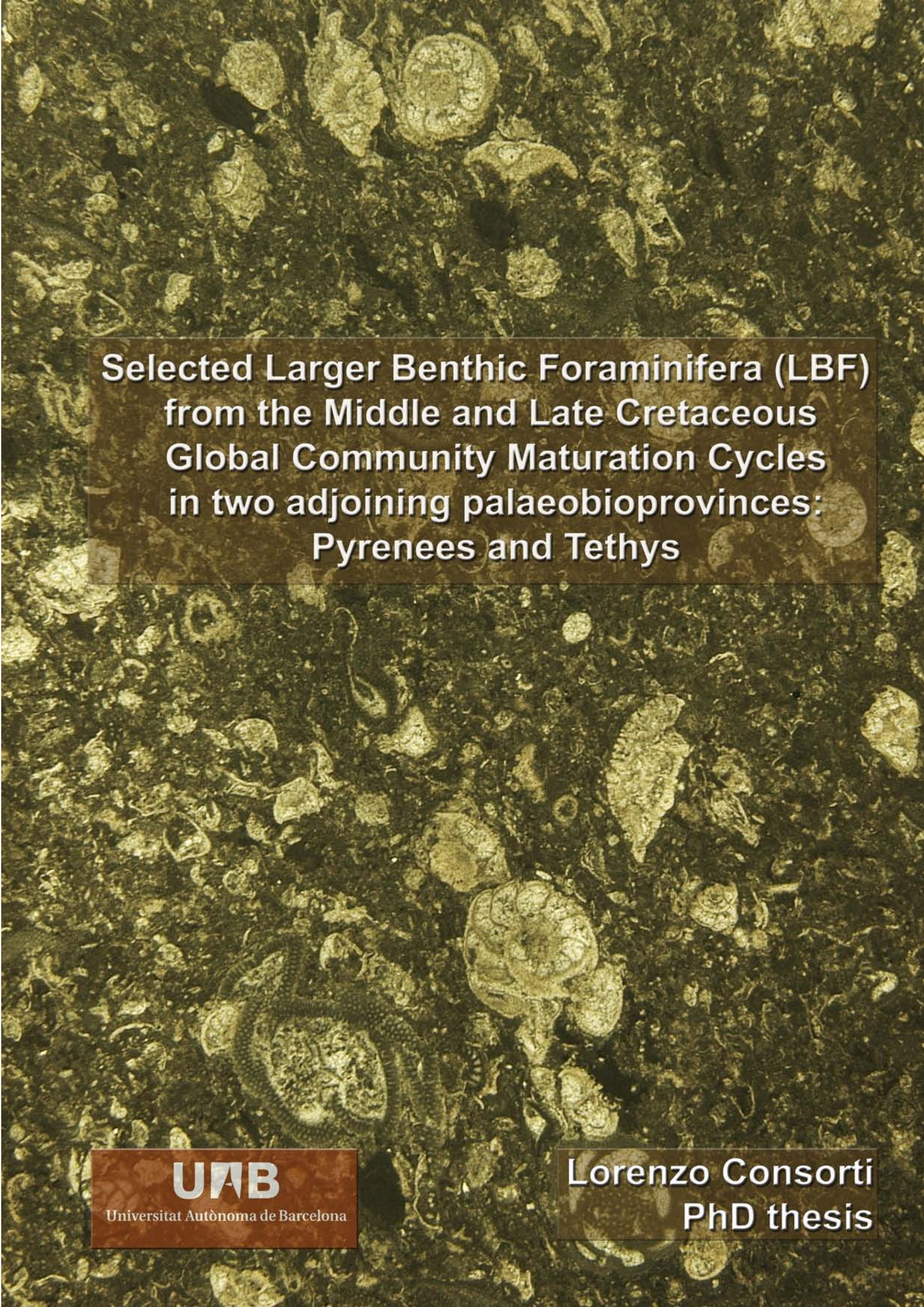
Universitat Autònoma de Barcelona

Selected Larger Benthic Foraminifera (LBF) from the Middle and Late Cretaceous Global Community Maturation Cycles in two adjoining Palaeobioprovinces: Pyrenees and Tethys

Lorenzo Consorti



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UAB
Universitat Autònoma de Barcelona

Lorenzo Consorti
PhD thesis

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Lorenzo Consorti
PhD Thesis
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Facultat de Ciències
Departament de Geologia
Unitat de Paleontologia

The achievement of the present memoir is by Lorenzo Consorti in order to apply for the degree of Doctor in Geology by the Universitat Autònoma de Barcelona, Departament de Geologia. The work has been entirely performed under the tutelage of Dr. Esmeralda Caus (Full Professor, Departament de Geologia, UAB)

Dr. Esmeralda Caus

Lorenzo Consorti

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Vidi ego, quod fuerant quondam solidissima tellum
Esse fretum, vidi factas ex aequore terras
Et procul at pelago conchae iacere marinae

I saw what was once firm land
Become the sea, I have seen earth made from the waters:
So far from the sea and sea shells there lying

Metamorphosis, XV, 262.
Publio Ovidio Nasone
(Sulmona, 43 B.C. - Tomi, act. Constantza, 18 A.C.)

In memory of my grandmother......

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Last but not means the least thanks to Pamela and my family for their encouragement, love, support, expertise, enthusiasm advice and for always being at my side through some tough times.

Abstract

Architectural and taxonomic study of selected larger benthic Foraminifera from the Upper Cretaceous of the Tethyan and Pyrenean paleobioprovinces is presented within a context of Middle and Late Cretaceous Global Community Maturation Cycles. Descriptions and determinations of the stratigraphic distributions of some new and revised taxa provide further data in reconstructing evolutionary trends among the larger benthic Foraminifera before and after the Cenomanian-Turonian boundary (CTB) extinction. This thesis includes five research papers presenting new data and reviewing existing knowledge from widespread localities (Spain, Italy and Iran). New perspectives are presented on soritoidean palaeobiogeography throughout the carbonate shelves and platforms of Tethyan Ocean during the peak of the Middle Cretaeous GCMC as well as a revision of *Praetaberina* (ex "*Taberina*" *bingistani*) from Southern Italy and Iran. The revision of *Praetaberina* and chemostratigraphy of the host strata show that the distribution of this genus is limited to the Upper Cenomanian where two species are described from the Apulian Platform and Zagros Mountains respectively. The report of Iberian soritoideans has been crucial in defining their stratigraphic distribution in a area that has been little studied. New data defining the recovery and the evolution of the foraminiferal communities after the Cenomanian-Turonian boundary extinction has enriched knowledge of the Late Cretaceous GCMC of the Pyrenean and Tethyan paleobioprovinces. The new rotaloideans described from these areas have been stratigraphically anchored by means of Strontium Isotope Stratigraphy indicating that two communities evolved separately in each palaeobioprovince. Diversification of these communities started at least during the late Turonian, but the exact timing remains unresolved. Finally the occurrence of the genus *Pseudorhapydionina* in the Santonian of the Pyerenean palaeobioprovince indicates that this genus was not affected by the Cenomanian-Turonian extinction event. *Pseudorhapydionina* was formerly considered to be confined to the Cenomanian within the Tethyan area but the new record presented here indicates its evolution in the Pyrenean area continued after the Cenomanian-Turonian boundary event.

Resumen

En la presente tesis se discuten los resultados de un estudio arquitectural y taxonómico sobre grandes Foraminíferos bentónicos cuya presencia caracteriza los ciclos de maturación global del Cretácico Medio y Superior. La descripción de nuevos taxones, acompañadas de consideraciones sobre su estratigrafía y distribución temporal, añade datos sobre el escenario evolutivo de los grandes Foraminíferos bentónicos que caracterizan las fases antecedentes y posteriores de la extinción ocurrida durante el limite Cenomaniense-Turoniense (CTB). La presente tesis incluye cinco artículos que presentan nuevos datos o revisan los existentes desde varias localidades (España, Italia, Irán). Se presentan nuevos datos sobre la distribución de soritoideos a lo largo de todos los ambientes carbonatados del Océano del Tethys durante el máximo del ciclo de maturación del Cretácico Medio como la revisión de *Praetaberina* (ex *Taberina bingistani*) desde sur de Italia a Irán. Este trabajo de revisión y los datos de estratigrafía isotópica muestran que la distribución del nuevo género se limita al Cenomaniense superior con dos especies; una desde la plataforma Apulica y la otra de las montañas de Zagros. El artículo sobre los soritoideos de la península Ibérica ha sido importante para definir la distribución estratigráfica de este grupo en una zona poco estudiada. Nuevos datos sobre la recuperación y la evolución de las comunidades de grandes Foraminíferos bentónicos después de la extinción del Cenomaniense-Turoniense enriquece el conocimiento sobre la dinámica del ciclo de maturación global del Cretácico Superior en las paleobioprovincias del Pirineo y del Tethys. Los nuevos rotaloideos que aquí se presentan han sido datados por medio de la estratigrafía de estroncio, indicando la existencia de dos comunidades que evolucionaron de manera separada en cada una de las bioprovincias. Sus diversificación empiezó en el Turoniense superior pero la exacta relación temporal entre ambas áreas queda sin resolver. Finalmente, la presencia de *Pseudorhapydionina* en el Santoniense de la paleobioprovincia del Pirineo indica que este género sobrevivió a la extinción del CTB. Hasta ahora *Pseudorhapydionina* habia sido considerada típica del Cenomaniense del Tethys, pero este hallazgo indica que su evolución continuó en el Pirineo después de la extinción del CTB.

Sommario

Nella presente tesi vengono esposti i nuovi risultati di uno studio sull'architettura e la tassonomia di alcuni grandi Foraminiferi bentonici che caratterizzano i cicli di maturazione globale del Cretacico Medio e Superiore. La descrizione dei nuovi taxa e le considerazioni sulla loro distribuzione stratigrafica e temporale arricchiscono lo scenario evolutivo dei grandi Foraminiferi bentonici che caratterizzano le fasi antecedenti e posteriori all'estinzione di massa avvenuta durante il limite Cenomaniano-Turoniano (CTB). La presente tesi si compone di cinque articoli che introducono nuovi dati o revisioni da varie località (Spagna, Italia, Iran). Nuovi dati sulla presenza di soritidi degli ambienti carbonatici dell'Oceno del Tetide sono stati rilevati durante l'apice del ciclo di maturazione globale del Cretacico medio (Cenomaniano). In questo contesto si inserisce la revisione del genere *Praetaberina* (ex "*Taberina*" *bingistani*) dalla Puglia e dall'Iran. Questa ricerca e i dati di stratigrafia isotopica ad essa correlati mostrano che la distribuzione del genere si limita al Cenomaniano superiore con due specie; una dalla Piattaforma Apula e l'altra dalla montagna degli Zagros. D'altro canto, l'articolo sui soritidi della penisola Iberica risulta importante nel definire la distribuzione stratigrafica del presente gruppo in una zona poco studiata sotto questo punto di vista. I nuovi dati sulla recuperazione e l'evoluzione delle comunità di grandi Foraminiferi bentonici dopo la crisi Cenomaniana-Turoniana aggiungono ulteriori tasselli alla ricostruzione della dinamica del ciclo di maturazione globale del Cretacico Superiore nelle paleobioprovince del Tethys e del Pireneo. I nuovi rotalidi provenienti da queste località sono stati datati utilizzando la stratigrafia degli isotopi dello stronzio indicando la presenza di due comunità che evolvono separatamente, ognuna confinata in una bioprovincia. La diversificazione delle comunità di rotalidi inizia nel Turoniano, ma l'esatta sincronia tra le due rimane ancora un nodo da sciogliere. Infine, la presenza di *Pseudorhapydionina* nel Santoniano del Pireneo indica che il presente genere è stato capace di sopravvivere all'estinzione del CTB. Fino a questo momento *Pseudorhapydionina* fu considerata tipica del Cenomaniano del Tethys, al contrario questa nuova scoperta indica che la sua evoluzione ebbe seguito nella paleobioprovincia del Pireneo dopo la crisi del Cenomaniano-Turoniano.

Goals and structure of the dissertation

Goals

This thesis focuses on selected larger benthic Foraminifera (LBF) from two groups: **the porcelaneous soritoideans (Superfamily Soritoidea) and the lamellar-perforate rotaloideans (Superfamily Rotaloidea)**. Both groups have structurally complex shells and are abundant in Upper Cretaceous shallow-water carbonate-platform deposits (Middle and Late Cretaceous GCM Cycles). Their high evolutionary rate and the possibility of identification in random thin sections of rocks that cannot be disaggregated, enhance their potential for use in biostratigraphy, palaeoenvironmental interpretations and palaeobiogeographic comparisons.

This thesis aims to contribute: (1) New data on **taxonomy** and test **architecture** of selected rotaloideans and soritoideans by formalising new species, genera and higher ranked taxonomic units thus resolving of some long-running controversies (e- g. the generic attribution of "*Taberina*" *bingistani* Henson) and filling the gap existing in the knowledge of Upper Cretaceous larger benthic Foraminifera; (2) Higher resolution **biostratigraphy** and chronostratigraphy by calibrating the stratigraphic position of taxa using chemostratigraphy; and (3) **Palaeobiogeographic comparisons** in order to give elements to assess similarities and differences between the Pyrenean and Tethyan palaeobioprovinces.

Structure

This thesis is presented as a compendium of research papers, which have been published or submitted for publication, accompanied by chapters that link the findings of these papers to the overall aims of the thesis.

The introduction (Chapter 1) is structured to provide a general idea on the main features of larger benthic Foraminifera, and their distribution in time and space. In sub-chapter 1.1 the characteristics of this group are briefly described: the shell architecture, reproduction and life strategies, and the factors conditioning their environmental distribution. These features are afterwards contextualized within the evolutionary mechanisms invoked in the Global Community Maturation Cycles (sub-chapter 1.2). Sub-chapter 2.3 introduces the concept of foraminiferal bioprovinces and the limits of Late Cretaceous paleobioprovinces, and sub-chapter 1.5 briefly outlines climatological, palaeoceanographical and palaeogeographical characteristics of the Atlantic shores of the European Continent and the Peri-Tethyan platforms during the Late Cretaceous. These areas were widely colonised by larger benthic Foraminifera, including the soritoideans and rotaloideans studied in the present thesis.

Chapter 2 focuses on the studied areas in the Iberian Peninsula (Pyrenees and Iberian Ranges in subchapters 2.1 and 2.2), Italian Peninsula (Central Apennines and southeastern Italy, in subchapter 2.3) and Iran (Zagros Mountains in subchapter 2.4). For each area a summary of the stratigraphy and biostratigraphy is given. A report on previous larger benthic foraminiferal data from each area is also presented.

Chapter 3 summarizes the provenance of the material and methodology used in this study. Results in the form of published papers are given in chapters 4 and 5.

In chapter 4 (“Constrains for the Middle Cretaceous GCMC”) the new data on the soritoideans and associated fauna from the Middle Cretaceous GCM Cycle are presented. In paper 1 (*Praetaberina new genus (type species: Taberina bingistani Henson, 1948): a stratigraphic marker for the Late Cenomanian*, published in Journal Foraminfieral Research), a new taxon, *Praetaberina* (species type *P. bingistani* Henson), has been described, solving the old controversy about the generic attribution of the Henson species. Moreover, a new species, *P. apula*, from the

Polignaro a Mare (Puglia, Southern Italy) has been described. In paper 2 (*Pseudorhapydionininae of the Iberian Ranges,* published in the Spanish Journal of Palaeontology) the pseudorhapydionines of Iberian Ranges are updated.

Chapter 5 ("Adding new data to the Late Cretaceous GCMC") deals with new data on soritoideans and rotaloideans from the late Cretaceous GCMC. In paper 3 (*Pseudorhapydionina bilottei sp. nov., an endemic foraminifera from the post-Cenomanian/Turonian boundary (Pyrenees, NE Spain)* published in Cretaceous Research) a new *Pseudorhapydionina* from the Lower Santonian deposits was presented. It represents the only *Pseudorhapydionina* in the Late Cretaceous GCMC. In this paper a new subfamily, Pseudorhapydionininae was established. Paper 4 (*Rotaloidean foraminifera from the Upper Cretaceous carbonates of Central and Southern Italy and their chronostratigraphic age*, published in Cretaceous Research) deals with the study of the rotaloideans of Lepini Mounts (Central Italy) and Cava Vitigliano (Puglia, Southern Italy), where the new taxa *Rotalispira vitigliana*, *R. maxima*, *Rotorbinella lepina*, *Pilatorotalia pignattii* and ?*Neorotalia cretacea* have been incorporated to the list of Cretaceous rotaloideans. Moreover, the structure of *Rotalispira scarsellai* and '*Stensioeina*' *surrentina* (Torre, 1966) has been re-studied. In paper 5: *New rotaliids (benthic foraminifera) from the Late Cretaceous of the Pyrenees*, summited to the Journal of Foraminiferal Research) refers to two new genera from the Campanian-early Maastrichtian of Pyrenees (Serres Marginals): *Suturina globosa* and *Rotalispirella acuta*.

Discussion of the results are given in chapter 6, whereas chapter 7 sets out the main conclusions of the study. Chapter 8 contains the bibliography pertaining to this thesis.

Chapter 1

INTRODUCTION

1.1 Larger Benthic Foraminifera

The Phylum Foraminifera d'Orbigny, 1826 (see Pawlowski et al., 2013, and the papers cited therein for discussion), comprises a wide group (fossil and living) of marine benthic and planktonic unicellular, eukaryotic and heterotrophic protistans with reticular pseudopods. The unicell is enveloped by a test which may be composed variously of organic (non-mineral) compounds, extraneous agglutinated grains, and biomineralised crystalline carbonate (calcite or aragonite). The building material of carbonate tests is either produced in the living protoplasm (Golgi vesicules) and transported to the site of wall construction as in carbonate-cemented agglutinated and porcelaneous foraminifera or by biomineralisation in protoplasm outside of the living test as in lamellar-perforate foraminifera.

Some foraminifera show continuous growth of the test (unilocular types), but the most common system of growth in foraminifera takes place by adding successive chambers (plurilocular shells) in discontinuous growth steps, called instars (Hottinger, 1978). The shapes and arrangements of chambers in plurilocular tests can be very different. Successive chambers communicate by means of one or multiple openings with the morphologies and positions of these in the apertural face very variable and apparently under functional control.

According to their dimensions, foraminifera are usually divided into "small" (usually less than 1 mm with simple chamber arrangements) and "larger" (usually more than 1 mm, most of them with complex morphology) that are informally termed "Larger Benthic Foraminifera" (LBF). Despite their unicellular nature, LBF shells can reach surprising sizes (for instance, up to 11 cm in diameter in the fossil *Nummulites maximus* d'Archiac), and the interior of their chambers have complex structures such as exoskeleton, endoskeleton, supplemental skeleton and a canal system (Hottinger, 1978, and the papers cited therein). **The present thesis deals with LBF.**

Reproduction cycles in LBF usually presents an alternation of generations (asexual and sexual) producing two distinct life stages: gamonts (haploid and uni-nucleate; called A-form) and agamont (diploid and multi-nucleate; called B-form), whose distinctive characters are marked in the tests (mainly in the first stages of growth and the overall size of the adult individuals). A more complex reproduction cycle comprising 3 different life stages (trimorphic cycles) are also possible by producing megalospheric schizonts (Zohary et al., 1980; Röttger et al., 1990; Dettmetering et al., 1998). Dimorphism (with small A-form and large B-form) permits the adoption in each generation of a different strategy of life: an opportunistic r-strategy or a conservative K-strategy (Hallock, 1987; Hohenegger, 2011; 2012, among others).

Living LBF host photosyntetic symbionts (chlorophyceans, rhodophyceans, dinophyceans or diatomaceans) in their protoplasm (Leutenegger,1984; Hallock, 1988; 1999; Lee and Anderson, 1991; among others). These features constrains their niches within the photic zone.

Larger Benthic Foraminifera are usual inhabitants of tropical and subtropical (more rarely temperate) shallow-water carbonate and mixed carbonate/siliciclastic environments. Most of them live in normal salinity waters while others may be present in unusual environments with periodic marine influences but with normal marine salinity (e.g. in Pete's pond, Australia: Shepherd, 1990; Aqaba Gulf: Zeiss and Hottinger, 1984). The LBF distribution depends on several interrelated factors such as temperature of the sea-water, light, nature of substrate and nutrient supply among others (Hottinger, 1983, 1990, 1997; Hallock, 1984, 1987; Reiss and Hottinger, 1984; Hallock and Glenn, 1986; Hohenegger, 1994, 1996, 2011; Renema and Troelstra, 2001; among others).

Temperature is a very important factor for LBF distribution. In low latitude warm waters LBF are present where temperature never drops below 14°C (minimum winter isotherm of water-surface) as for instance amphisteginids, but others like *Archaias* or *Operculina* need higher temperature to survive (Langer and Hottinger, 2000). Under some oceanographic conditions, the presence of LBF is constrained by warm-water current patterns, which extend their presence into higher latitudes than usual (e.g. Leeuwin current in Western Australia, Semeniuk, 2001; Kendrick et al., 2009). Salinity is also an important parameter driving the distribution of LBF; some forms tolerate strong changes in water salinity becoming able to thrive in hypersaline conditions (e.g. in Shark Bay, Western Australia; see fig. 8 and 9 of Mossadegh et al., 2009).

Larger Benthic Foraminifera occupy all depth-niches within the photic zone. Their depth position in the water-column depends on the requirements of their symbionts (Leutenegger, 1984; Hottinger, 1997; Hollaus and Hottinger, 1998; Hottinger 2006; among others). Moreover, the penetration of the light at the sea-bottom depends on water quality; in clear water the light can penetrate as far as 140m or even more (e.g. Gulf of Aqaba, Zeiss and Hottinger, 1984), but in areas with a considerable amount of terrigenous supply (with nutrient excess), river delta or estuarine environments (Billmann et al., 1980; Hallock and Schlager, 1986; Haig, 2002; Narayan and Pandolfi, 2010), the penetration of light and subsequent foraminiferal distribution in water column is much more reduced.

Some LBF are adapted to hard or soft substrate, while others leave independently of the substrate (Hottinger, 1977; Reiss and Hottinger, 1984). In recent environments, *Ammonia catesbyana* d'Orbigny or *Elphidium excavatum* (Terquem) are strictly infaunal, caught screwing in soft substrates (Langer et al., 1989). Flat porcelaneous and lamellar forms like *Sorites* Ehrenberg, *Planorbulina* d'Orbigny or *Amphisorus* Ehrenberg are mostly epiphytic on seagrass leaves (Reiss and Hottinger, 1984; Langer, 1993; Fujita and Hallock, 1999; Hottinger, 2006), while others lives in hard substrates, like the strong-ornamented *Calcarina spengleri* (Gmelin) (Hohenegger, 1994).

Most of the ecological and environmental parameters mentioned above for recent LBF have been used in the fossil studies to build distribution models using methods of comparative anatomy (for instance: Hallock and Glenn, 1996 or Mossadegh et al., 2009 for the Cenozoic; Romero et al., 2002, for the Palaeogene; Caus, 1988 and Robles et al., 2013 for the Upper Cretaceous, among others).

1.2 Global Community Maturation Cycles

In the geological past, starting from the Late Carboniferous, the same ecological niches were inhabited by different LBF assemblages that evolved in subsequent global community maturation cycles (GCMC). These cycles are bounded by global palaeoenvironmental crises characterized by increased extinction rate or even by mass extinctions causing the partial loss of information accumulated by LBF during the previous cycle. The concept of GCMC has been firstly introduced in literature by Hottinger (1998; 2001) in order to conceptualize the mechanisms of extinction and recovery in the LBF communities, each GCMC is defined as the time of continuous, gradual biotic changes between two extinctions events in which LBF may be able to gradually reach a full K -strategy, diversifying and colonizing most of the ecological niches available in shallow-water platform settings even including migration mechanisms or endemism. The process works on geological time and is based on morphological phenotype observation (genera and species).

In the foraminiferal fossil record, the Palaeocene-Eocene GCMC has been studied in most detail (Hottinger, 1998; 2001). By comparison, the older GCM cycles are poorly known. In the first phase of Palaeocene-Eocene GCMC of the Peri-Mediterranean area small r-strategists ruled after the Cretaceous/Paleogene boundary (K/Pg) mass extinction and no K-strategists are present. After that, generic diversity starts to rise producing monospecific genera with weak dimorphism, and many of the genera are cosmopolitan. Later, the successful genera increase in species diversity by parallel evolution to inhabit available niches. The increase in size of some dominant taxa coincides with a peak in optimum ecological conditions. In this phase, endemism is frequent. The latest phase is indicated by the appearance of new genera (competitors) besides the old ones (Hottinger, 2001). The tendency of LBF to develop different stages of community maturation in time is also a basic notion in framing the biozonation charts in shallow-water settings (e.g. Chauzac and Poignant, 1997; Serra-Kiel et al., 1998; Caus et al., 2010).

The LBF studied in this thesis belong to middle Cretaceous (MKGCM) and Late Cretaceous (LKGCM) cycles. The Middle and Late Cretaceous GCM cycles are separated by an extinction event at the Cenomanian-Turonian boundary (CTB), which wiped out all the extreme and moderate k-strategist LBF (Caus et al., 1997; Hart et al. 2005; Parente et al.,2008). Although these were not formally defined for the LKGMC and MKGCMC, they were mentioned in several works (Hottinger and Caus, 2009; Caus et al., 2009; Goldberg and Langer, 2009; Boix et al., 2009, 2011; Caus et al., 2013; Consorti et al., 2015; Arriaga et al., 2016; among others).

The LBF of the last phases of the Middle Cretaceous GCMC (Cenomanian) are mainly represented by the porcelaneous alveolinoideans (Alveolinidae and Rhapydioninidae) and soritoideans associated with agglutinated foraminifera (mainly orbitolinids, dicyclinids and nezzazatids). The lamellar perforate foraminifera are represented by small rotaloideans (the oldest species of *Rotorbinella* Brady and *Pararotalia* Le Calvez). Towards the end of the Cenomanian almost all the LBF disappear. As shown by Parente et al., (2008), at least in the Southern Italy where shallow-water carbonate sedimentation was continuous through the CTB transition, the extinction occurred in two successive phases separated by 150ky: in the first phase the K-extreme LBF like the alveolinoideans disappeared, while in the second one all the soritoideans and many larger agglutinated Foraminifera were also eliminated. In other areas where shallow-water carbonate sedimentation was interrupted by an eutrophication event and a drowning episode (Caus et al., 1993; 1997; Hart et al., 2005; Consorti et al.,2015; Arriaga et al., 2016) all the LBF were wiped out simultaneously near the end of the Cenomanian. The cosmopolitan small-sized *Rotorbinella* and *Pararotalia* genera with relative simple umbilical architecture and apparent lack of dimorphism survived through the CTB Event (Boix et al., 2009; Consorti et al., 2017).

In the few areas where shallow-water carbonate sedimentation persisted across the CTB boundary, the Late Cretaceous GCMC starts with small, morphologically simple taxa (see Arriaga et al., 2016 for details), but LBF with K-strategy did not recover until, at least, the middle Coniacian-Santonian (Boix et al., 2009; Boix et al., 2011). At that time new porcelaneous K-strategist LBF appear, like soritoideans, alveolinoideans and meandropsinids (Hottinger et al., 1989; Caus et al., 2013; Vicedo et al., 2009, 2012). The agglutinated dicyclinids are also common as several taxa like *Calveziconus* Caus and Cornella, *Montsechiana* Aubert, Costau and Gendrot or *Ilerdorbis* Hottinger and Caus new to the late Cretaceous GCMC. Concerning the lamellar perforated LBF, during the Coniacian-Santonian a diversification takes place of the rotaloideans (Boix et al., 2009; Consorti et al., 2017; Consorti et al., in rev). Starting from the Campanian, the Late Cretaceous GCMC is dominated by lamellar perforate LBF, with three groups: orbitoidids, lepidorbitoidids and siderolitids, which occupy all the niches in the photic zone, while the porcelaneous and agglutinated LBF are restricted into the shallowest zone.

1.3 Late Cretaceous Larger Benthic Foraminifera bioprovinces

Worldwide LBF distribution in modern oceans is controlled by several oceanographic and ecological constraints. Temperature of the surface water is the primary factor controlling the LBF distribution as it is for hermatipic stony corals (Langer and Hottinger, 2000). However, the distribution of each taxon is constrained by a temperature minimum that can be tolerated by the particular species (some species are more tolerant than others, see for instance, text-fig. 7 in Langer and Hottinger, 2000). Ocean trophism, associated to oceanic circulation patterns, also plays an important role in the distribution of Foraminifera at the same temperature gradient performing longitudinal oceanic discontinuities in LBF composition (Hallock, 1987). The presence or absence of some selected genera in key localities and their dispersal patterns globally define four bioprovinces (Inner Central Pacific province, Central Indopacific realm, Western Indian Ocean -including the Red Sea and the Persian Gulf-, and Caribbean realm) in modern oceans (in Langer and Hottinger, 2000).

In the Late Cretaceous, the LBF distribution follows the same global pattern to that of the present-day LBF, but distributions are constrained by physical characteristics of the Earth at each period (e. g., palaeogeography, climate, Oceanic circulation, among others; see Caus and Hottinger, 1986; Caus, 2007; Goldberk and Langer, 2009). Globally, Goldberk and Langer (2009) identified four faunal palaeobioprovinces for the Coniacian-Maastrichtian interval: Caribbean (CFP), European (EFP), African (AFP) and Asian (AFP), which extended from 50º palaeolatitude North to 40º palaeolatitude South. Caus and Hottinger (1986) and Caus et al. (2007) differentiated three East-West LBF palaeobioprovinces: Caribbean, Pyrenean and Tethyan. The Caribbean palaeobioprovince corresponds to the southern United States, Mexico, Central America, Caribbean Islands and northern South America. However, some taxa that are characteristic from this palaeobioprovince reached the Pacific Islands; therefore, the Caribbean palaeobioprovince extended further than just the American Continent. This palaeobioprovince coincides with the CFP of Goldbeck and Langer (2009). The Pyrenean (Atlantic) palaeobioprovince corresponds to both margins of the Pyrenean Basin extending north-ward into the European Continent (the Chalk Sea); it corresponds partially to the EFP of Goldbeck and Langer (2009). The Tethyan palaeobioprovince extends from the south-east of the Iberian Peninsula to the Middle

East, and comprises the Iberian Ranges in Spain, Apenninic and Apulian platforms in the south of Italy, the Adriatic plataforms (Friuli, Adriatica, Kruja), Greece (Gavrovo-Tripolitza), South of Turkey (Taurides) and the Middle East platforms (Syria, Iraq, Zagros and Oman). This palaeobioprovince comprises partially the Asian (AFP) and African (AFP) faunal palaeobioprovinces of Goldbeck and Langer (2009). **The LBF studied in the present work are located in two adjoining palaeobioprovinces: Tethyan and Pyrenean** *sensu* **Caus et al. (2007).**

Concerning the LBF distribution, the current knowledge suggests that in the Middle Cretaceous GCMC the porcelaneous LBF show a great degree of endemism, which occurred within the Pyrenean and Tethyan palaeobioprovinces, and also within the western, central and eastern Tethyan paleobioprovince. For instance, among the alveolinoideans the representatives of the praealveolinids are present in both palaeobioprovinces, but the sellialveolines (Rhapydioninidae) are only present in the Tethyan palaeobioprovince (Calonge et al., 2002; Caus et al., 2009; Vicedo et al., 2011; Piuz et al., 2014; Vicedo et al., 2016; among others). The soritoidean pseudorhapydionines (De Castro, 1972; Caus et al., 2009; Consorti et al., 2015; Consorti et al., 2016b) occur only in the Tethys. The agglutinated and lamellar perforate LBF seem to be less palaeogeographically restricted, although few detailed works have been published on this subject.

In the Late Cretaceous GCMC, most of the newly evolved porcelaneous K-strategist taxa included more or less endemic genera and/or species in each palaeobioprovince (Fleury et al., 1985; Caus and Hottinger, 1986; Caus et al., 2009). The large meandropsinids are restricted to the Pyrenean palaeobioprovince (Hottinger and Caus, 2009). Representatives of the fabulariids (lacazines) are also typical from the Pyrenean area, but they extend also in the western Tethyan palaeobioprovince (Hottinger et al., 1989). The rhapydioninids were widely distributed along the Tethyan palaeobioprovince but are absent in the Pyrenees, where the alveolinoideans are only represented by the alveolinid *Hellenalveolina* Hottinger, Drobne and Caus in the southern margin and *Fabalveolina* Vicedo, Aguilar, Caus and Hottinger and *Subalveolina* Reichel in the northern margin (Vicedo et al., 2009). Other porcelaneous genera like *Keramosphaerina* Stache, *Scandonea* De Castro, *Murgella* Luperto sinni and *Cuneospirella* Cherchi, Schroeder and Ruberti seem to be typical of the Tethyan palaeobioprovince while *Broeckina* Munier-Chalmas seems to be restricted to the Pyrenean one. The genus *Lamarmorella* (Cherchi and Schroeder,

1974) is only present in Sardinia (West of Italy).

Concerning the lamellar perforate LBF, the orbitoidids, lepidorbitoidids and siderolitids are common in both palaeobioprovinces. Rotaloideans are also present in both palaeobioprovinces, but almost the totality of the konwn genera are restricted to one or other palaeobioprovince (Consorti et al. 2017; Consorti et al., in rev). Few data have been published on the distribution of the agglutinated LBF. Dicyclinids and dictyopsellids are known in both palaeobioprovinces as well as the agglutinated conical foraminifera *Calveziconus* Caus and Cornella (Velić, 2007, Frijia et al., 2015).

1.4 Pyrenean and Tethyan Cretaceous shallow-water environments

The Late Cretaceous is a period in the Earth History characterized by greenhouse conditions, in which mean annual temperatures were somewhat higher than the present-day. This was in particular enhanced by the little or almost ephemeral presence of polar ice sheets (less than 3% of the Earth surface, Miller et al., 2003), the existence of wide interior seaways (e.g. Western Interior in USA and Trans-Saharan in northern Africa) and the warm circum-global Tethyan current, which homogenized water surface temperature around the equatorial belts (Goldbeck and Langer, 2009; Hay, 2011). Moreover, the high sea-level (Haq et al., 2014) resulted in the widespread distribution of wide carbonate shelves and platforms over the equatorial, tropical and sub-tropical belts. The shallow-water deposits cropping out today in the Pyrenean, Peri-Mediterranean (Western and Central Tethys) and Middle East areas, which were positioned between 35 degrees latitude N and the equator (Philip and Floquet, 2000; Hay, 2009; Zarcone et al., 2010) were part of extensive carbonate shelves.

In detail, Cretaceous shallow-water deposits of Pyrenees are from the southern and northern margin of the Pyrenean Basin, which was a narrow gulf developed between Iberia and Europe, and surrounded by emerged lands (Ebro Massif, French Central Massif and Sardinia-Corsica Block, at the east (Philip and Floquet, 2000). The Pyrenean gulf was opened to the north-west and influenced by north Atlantic oceanic currents giving direct communication with the northern European basins (Fleury et al., 1985; Rat, 1987; Caus and Hottinger, 1986). The Late Cretaceous sedimentation in the Southern Pyrenean epicontinental shelf was predominantly carbonate and/or mixed carbonate-siliciclastic. It was located between 30 and 35 degrees latitude north (Philip and Floquet, 2000).

The palaeogeography of the Tethyan area was much more complex, and includes three subareas. Westward, the Iberian basin was an epicontinental, shallow carbonate shelf receiving terrigenous input from the surrounding emerged land (Mas and Salas, 2002). In contrast, the Central Tethys comprised a set of isolated intra-oceanic carbonate platforms separated by troughs inherited from Early Jurassic extensional phases, and was tectonically inactive until the Late Eocene (Pons and Sirna, 1992; Zarcone et al., 2010, Carminati and Doglioni, 2012; Cardello and Doglioni, 2014). These platforms were disposed between the 25° and 15°N palaeolatitude (Philip and Floquet, 2000) comprising the italian ACP (Apennine Carbonate Platform), AP (Apulian Platform), AD in the balkans (Adriatic Platfrom) and the greek Gavrovo-Tripolitza Platform (GTP). During Cenomanian, the Panormide (Pn, Sicily) and Constantine (CsP, Tunisia) platforms also received shallow-water sedimentation, and consitute the bridge connecting Africa and Adria plates (see Zarcone et al., 2010 and Fig. 9 and 10). The Tethyan Ocean was lapped by the warm circum-global Tethyan current (Poulsen et al., 1998) flowing predominantly eastward during middle Cretaceous times, while westward during Late Cretaceous (Fleury et al., 1985, Trabucho-Alexandre et al., 2010, Hay, 2011, see in particular fig. 6 B,C of Hay, 2009). To the south-east, the Middle East Upper Cretaceous platform outcropping in Iran (Zagros Mountains) formed part of an epicontinental carbonate shelf attached to the Arabian Shield and located within the equatorial belt.

Chapter 2

STUDY AREAS

The thesis work has been done in three main geographical areas, that from west to east are: A) Iberian Peninsula – Pyrenees and Iberian Ranges; B) Italian Peninsula – Central Apennines and southeastern Italy; and C) North-West and Central Iran, Fars – Zagros Mountains (Fig. 1).

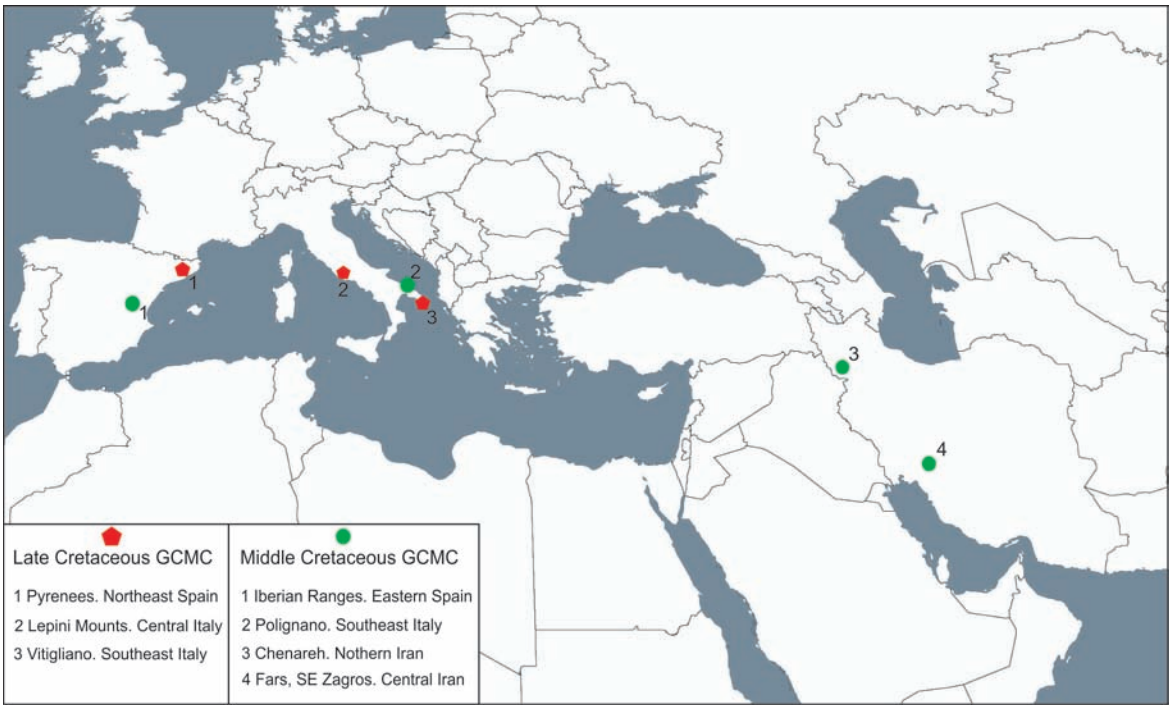

Fig. 1 - Map showing the localities here in study.

2.1 Pyrenees

The Pyrenees is a double vergent mountain belt resulting from the collision between the Iberian and European plates (Roest and Srivastava, 1991). The Orogen extends from the Galician margin at the west to the South of France (western Alps) at the east. The area of study corresponds to the central part of the Pyrenees, the so-called "Aragonese-Catalan Pyrenees" (subdivided into west-central, central and eastern Pyrenees), which is separated from the Basco-Cantabrian Pyrenees at the west by the Pamplona fault (see Fig. 15.4 in Muñoz, 2002). Within the Aragonese-Catalan Pyrenees, the area of study belongs to the Central and Eastern Southern Pyrenees. The former corresponds to the South Pyrenean central unit (Seguret, 1972), and is divided, from north to south, into three main tectonic units: Bóixols, Montsec and Serres Marginals thrust sheets (Muñoz, 1992), whereas in the Eastern Pyrenees two main tectonic units are identified:

Pedraforca and Cadí thrust sheets (Vergés, 1993). The studied samples come from the Montsec, Serres Marginals and Pedraforca thrust sheets, and belong to the Late Cretaceous GCM Cycle. The lack of lateral continuity between the deposits of these three thrust sheets led in the past to a diverse formal and informal lithostratigraphic nomenclature. However, in this work a unified set of stratigraphic units (taken from the Montsec thrust sheet) is used in order to better comprehend the distribution of the studied larger Foraminifera, The Upper Cretaceous (Cenomanian-Maastrichtian) deposits are represented, from the base to the top, by the following stratigraphic units:

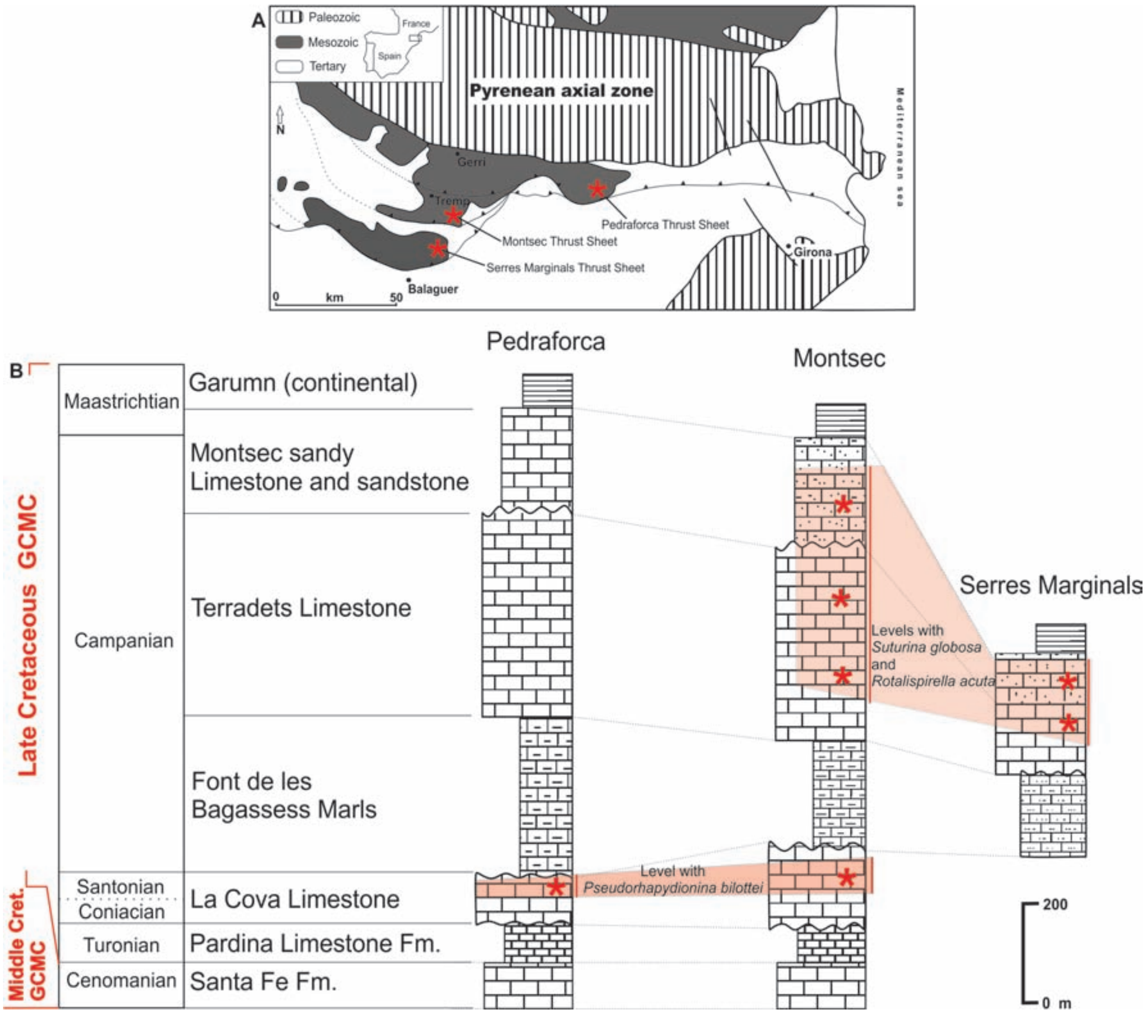

Fig. 2 - A: Southern Pyrenees map showing the position of Serres Marginals, Montsec and Pedraforca tectonic units. B: Correlation between the three Upper Cretaceous series with the stratigraphic distribution of the new taxa described in this thesis. Asterisks indicate the position of the analyzed samples.

a) Santa Fe Formation (Mey et al., 1968, emended Caus et al., 1993). This unit, which rests unconformably on Lower Cretaceous or Jurassic deposits, consists of praealveolinid limestones deposited in a shallow platform environment. It is uniformly distributed in the Montsec and Pedraforca thrust sheets, but is absent from the Serres Marginals thrust sheet. Its age is middle-late Cenomanian (Hottinger and Rosell, 1973; Calonge et al., 2002). The main LBF are *Praealveolina tenuis*, *Ovalveolina ovum* and *P. simplex* associated with nezzazatids and rare agglutinated and lamellar-perforated LBF. The LBF from this unit belongto the Middle Cretaceous GCM cycle.

b) Pardina Limestone Formation (Caus et al., 1993). This unit consists of grey micritic limestone bearing calcispheres and planktonic foraminifera from the *Helvetoglobotuncana helvetica* and *Marginotrucana schneegansi* zones. The age is Turnonian (Caus et al., 1993) and the formation represents a major environmental change in the basin, from shallow to deep marine. This unit lacks LBF. It is present in the Montsec and Pedraforca thrust sheets.

c) La Cova Limestone (Pons, 1977). This formation unconformably rests on the Pardina limestone and consists of shallow-water massive and nodular marly limestones with abundant larger-benthic Foraminifera, molluscs (including rudists), oysters, and corals as the most conspicuous constituents. The LBF have been widely studied (Cherchi and Schroeder, 1975; Boix et al., 2011; Consorti et al., 2016). The chronostratigraphic age fixed by Strontium Isotope Stratigraphy (SIS) is middle Coniacian–middle Santonian (Boix et al., 2011). It is well represented in the Montsec and Pedraforca thrust sheets, but is absent from the Serres Marginals thrust sheet.

d) Font de les Bagasses Marls (Pons, 1977). Grey and yellow calcareous marls with larger Foraminifera, echinoids, corals, rudists, brachiopods and calcareous algae characterise this formation. For the foraminiferal content see Hottinger et al., (1989), Boix (2007), and Albrich et al. (2014, 2015). The age of the unit calibrated by means of SIS is early Campanian (Albrich et al., 2014). In the Serres Marginals thrust sheet the formation consists of sands, clays, conglomerates and rarely marls.

e) Terradets Limestone (Pons, 1977). Grey to beige mainly bioclastic limestone with mainly larger Foraminifera, rudists, bryozoa and calcareous algae characterise the formation. Villalonga (2009, and papers cited therein), Raquel-Robles (2014) and Consorti et al. (in rev) documented the Foraminifera. The age of the Terradets Limestone, by means of SIS, ranges from early to late Campanian (personal communication of Prof. Mariano Parente and Gianluca Frijia). In the Marginals thrust sheet, the Terradets Limestone is partially equivalent to the Serres Marginals Limestone of Souquet (1967).

f) Montsec Formation (sandy limestone and sandstone) (Pons, 1977). Calcareous sandstones and sandy limestones with larger Foraminifera, bryozoans, brachiopods and rudists at particular levels characterise this unit. For information about the LBF see Villalonga (2009) and Consorti et al. (in rev.). The age is latest Campanian–earliest Maastrichtian (Caus et al., 2016 and the papers cited therein). This formation contains the last marine Cretaceous deposits in the Central and Eastern Southern Pyrenees and is overlian by the Tremp Group, which contains dinosaur remains. In the Serres Marginals thrust sheet, sandy limestones form this unit.

In Figure 2B correlation between the Upper Cretaceous deposits of the three tectonic units is presented. **The studied LBF are from La Cova limestone, Terradets and Montsec sandy limestone and sandstone units.**

2.2 Iberian Ranges

The Iberian Ranges consist of a NW–SE striking intra-plate belt extending for a length of ~400 km and a width of more than 200 km on the eastern Iberian Peninsula, and surrounded by the Ebro, Duero and Madrid basins and the Valencia trough (see Fig. 15.13 in Simon et al., 2002). Within the Iberian Ranges five structural units are identified: the Demanda-Cameros (NW), Aragonian branch (central NE), Maestrazgo (SE), Castilian branch (central SW) and Sierra de Altomira (SW) units (see Fig. 1a in Consorti et al., 2016b). The Catalanids are included in this last unit. The samples studied in this thesis come from the Castillian branch and the Maestrazgo unit.

Shallow marine deposits, after Vilas et al. (1982), are divided into the following five lithostratigraphic units, from bottom to top (Fig. 3).

a) Aras de Alpuente Formation. Brown bioclastic limestones with fragmented bivalves (including rudists), gastropods and larger Foraminifera including mainly orbitolinids and *Involutina hungarica* (Sidó) comprise this unit. The age of this formationis Albian (Caus et al., 2009).

b) Chera Formaiton. This unit consists of an alternation of green marls very rich in oyster banks and bioclastic limestones bearing larger Foraminifera, mainly agglutinated types (orbitolinids and cuneolines) and the porcelaneous *Sellialveolina quintanensis*, *Ovalveolina macagnoe*, small *Praealveolina* and *Pseudorhapydionina*, and *Peneroplis parvus*. The age attributed to the formation is earliest Cenomanian (Calonge et al., 2002; Caus et al., 2009).

c) Alatoz Formation. Laminated limestones and dolostoneare the main components of this unit. It contains orbitolinids, *Charentia cuvillieri* and *Praealveolina iberica*. The age is early Cenomanian (Caus et al., 2009).

d) Villa de Ves Formation. This unit comprises marly massive limestones intercalated with marly limestones passing upwards to dolostone. The larger Foraminifera are represented by orbitolinids, nezzazatids, *Praealveolina debilis* and *Sellialveolina gutzwilleri*. The suggested age is middle Cenomanian.

e) Casa Medina Formation. The formation consists of nodular limestones and dolstones with praealveolinids and pseudorhapydioninids, which are dated as late Cenomanian (Calonge et al., 2002; Caus et al., 2009).

f) Ciudad Encantada and Sierra de Llaveria Formations. These consist of dolomites and massive limestones with some praealveolines and pseudorhapydionines. The age is late Cenomanian (Calonge et al., 2002; Caus et al., 2009).

All the formations represent the Middle Cretaceous GCM cycle in the Iberian Ranges. As in the Pyrenees, the end of the Middle Cretaceous GCMC is marked by an eutrophication event and the drowning of the platform (Calonge et al., 2002). The Turonian deposits are represented by micritic limestones with calcispheres and planktonic Foraminifera.

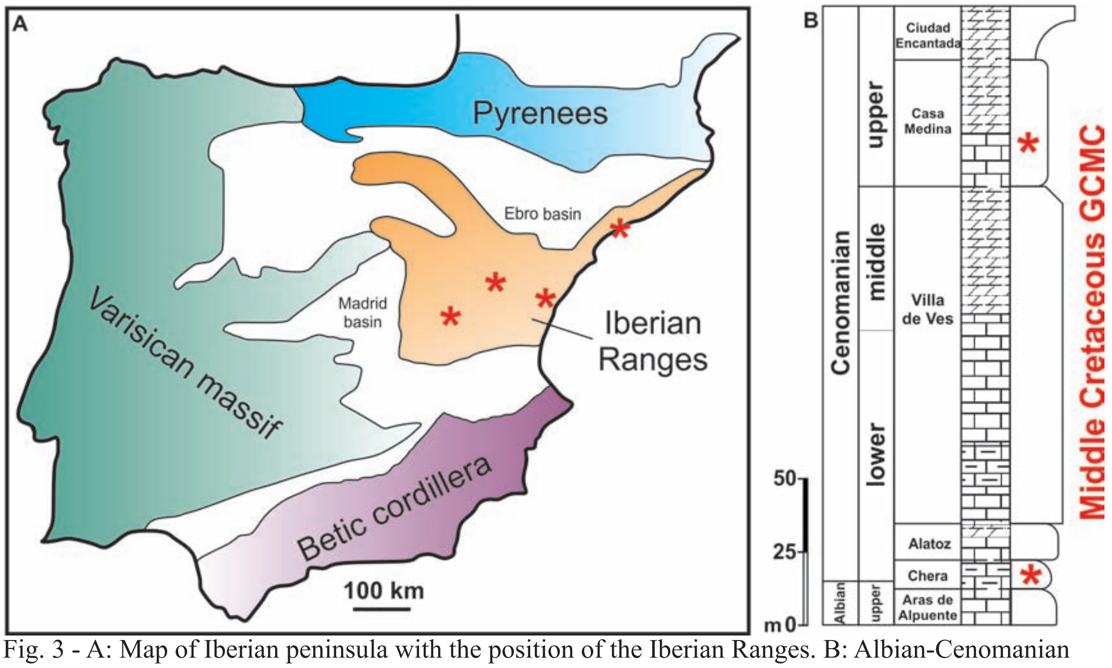

Fig. 3 - A: Map of Iberian peninsula with the position of the Iberian Ranges. B: Albian-Cenomanian formations cropping out in the Iberian Ranges. Asterisks indicate the position of the analyzed samples.

2.3 Central Apennines and Southeastern Italy

During Mesozoic, the area of the future Central Apennines was part of the large, Bahamian-type carbonate platform–basin system of the Adria microplate (Bosellini, 2002; Zarcone et al., 2010). Platform configuration was driven by syn-sedimentary faulting and folding of different ages starting with continental rifting during the Late Triassic–Early Jurassic (Cardello and Doglioni, 2014). The central Apennines tectonic emplacement started during the Miocene and this is today represented by folds and thrust-belt structures verging eastward (Accordi, 1966, Cosentino et al., 2010). **In the present thesis the Lepini Mountains in central Italy (Latium) and Puglia in south-eastern Italy are studied with particular focus on Rotaloidean LBF.** The Lepini Mounts jointly with the adjacent Ausoni and Aurunci Mounts, comprise a continuous mountainous spine formed by a thick series of Mesozoic shallow-water carbonates (Accordi, 1966). Three stratigraphic units represent the Upper Cretaceous in this area, listed below from bottom to top.

a) Alveolinid and Nezzazatid Limestone and Dolostone unit. This is characterized by alveolinoideans (*Cisalveolina*, *Sellialveolina* and *Praealveolina*) and soritoideans (Pseudorhapydioninae) LBF, which belong to the Middle Cretaceous GCMC (Cenomanian after Chiocchini, 1977; Centamore et al., 2007).

b) Radiolitid Limestone unit. This was deposited within an inner-shelf environment colonized by rudists and characterised by peritidal cycles. As a whole, the LBF assemblage includes *Accordiella conica*, *Rotalispira scarsellai*, '*Stensioeina*' *surrentina*, *Moncharmontia apenninica*, *Orbitoides media* and *Scandonea mediterranea* (Angelucci and Devoto, 1966; Devoto and Parotto, 1967; Centamore et al., 2007; Mancinelli et al., 2003; Chiocchini et al., 2012). The age of the unit ranges from Turonian to Campanian (Di Stefano et al., 2011, Frijia et al., 2015).

c) Detrital-skeletal "saccharoidal" or "crystalline" Limestone unit. This contains *Siderolites*, *Orbitoides*, *Rhapydionina* and *Laffiteina*, that mark the end of Cretaceous sedimentation in Central Italy (Cosentino et al., 2010). The age is late Campanian to Maastrichtian (Colacicchi, 1967; Carbone and Catenacci, 1978).

In other areas of the Central Apennines, these stratigraphic units are few represented, absent and/or replaced by karts and bauxite deposits (Accordi et al., 1987; Mancinelli et al., 2003;

Cosentino et al., 2010).

Unit b and the unit c belong to the Late Cretaceous GCMC. **The samples studied here come from the Radiolitid Limestone**.

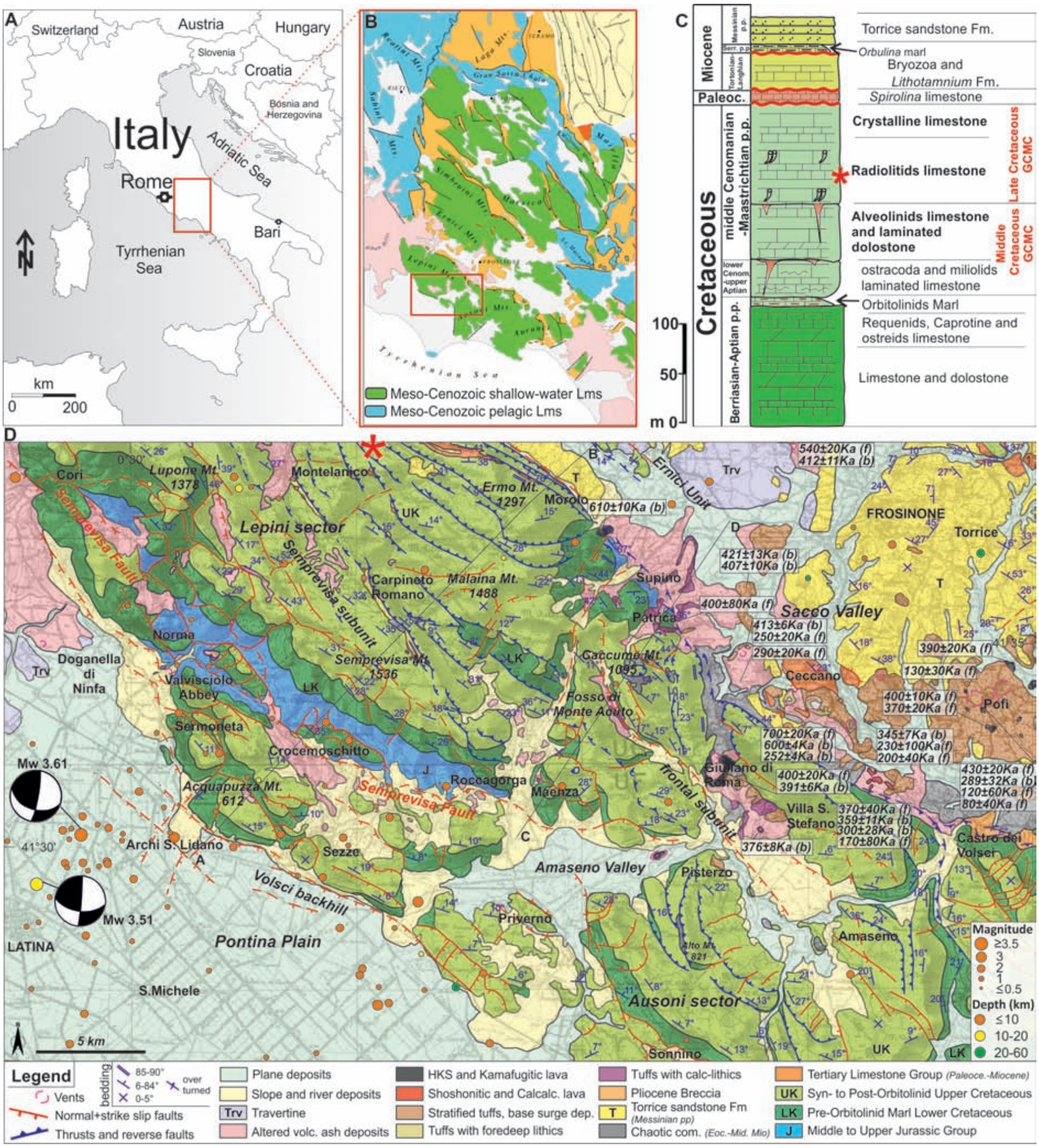

Fig. 4 - A and B: Map of Italy and geological map (from Cosentino et al., 2010) of the Central Apennines.C: Syenthetic column -Cretaceous and Neogene- of the Lepini area (taken and simplified from Chiocchini and Mancinelli, 1977 and Centamore et al., 2007). Asterisck indicate the position of the studied samples. D: Geological Map of the Lepini and Ausoni sector (from Cardello and Consorti, in prep.). Asterisk indicates the position of the studied column near Gorga.

The carbonatic spine of Puglia (SE Italy) is a series of shallow-water Mesozoic rocks up to 6000m thick (Ricchetti et al., 1992). Due to its position, this part of the Adria microplate has been only slightly ideformed during the Apenninic compressional phase (Doglioni et al., 1994). As a result, shallow-water carbonates are only slightly tectonized. In this thesis two sectors have been studied: Murge and Salento.

In the Murge sector (central Puglia) the Upper Cretaceous is represented by the following stratigraphic units.

a) Bari Limestone.This formation consists of limestones of Albian–Cenomanian age. The upper part of the unit (Cenomanian) contains a rich fauna of LBF (*Pseudorhapydionina*, *Pseudorhipidionina*, *Crysalidina*, *Cisalveolina*, *Sellialveolina*, *Nezzazata*, and *Praetaberina*) with a few rudist-rich levels. The top of the unit is marked byan erosive surface with bauxite (Fig. 5). The unit belongs to the Middle Cretaceous GCMC and has been studied in this thesis.The bauxite level marks the boundary with the overlying Calcare di Altamura (Luperto Sinni and Reina, 1996; De Castro, 2006; Spalluto and Caffau, 2010; Spalluto, 2012; Consorti et al., 2015).

b) Altamura Limestone. This lower Coniacian to Santonian unit contains LBF including *Accordiella conica*, *Moncharmontia apenninica* and small rotaloideans (Luperto Sinni and Reina, 1996).

c) Caranna Limestone. This is characterized by limestones with *Orbitoides* and siderolitids (Luperto Sinni and Reina, 1996). In some localities *Cuvillierinella*, *Murciella* and *Rhapydionina liburnica* are present. The age of this unit is Campanian-Maastrictian (Reina and Luperto Sinni, 1993).

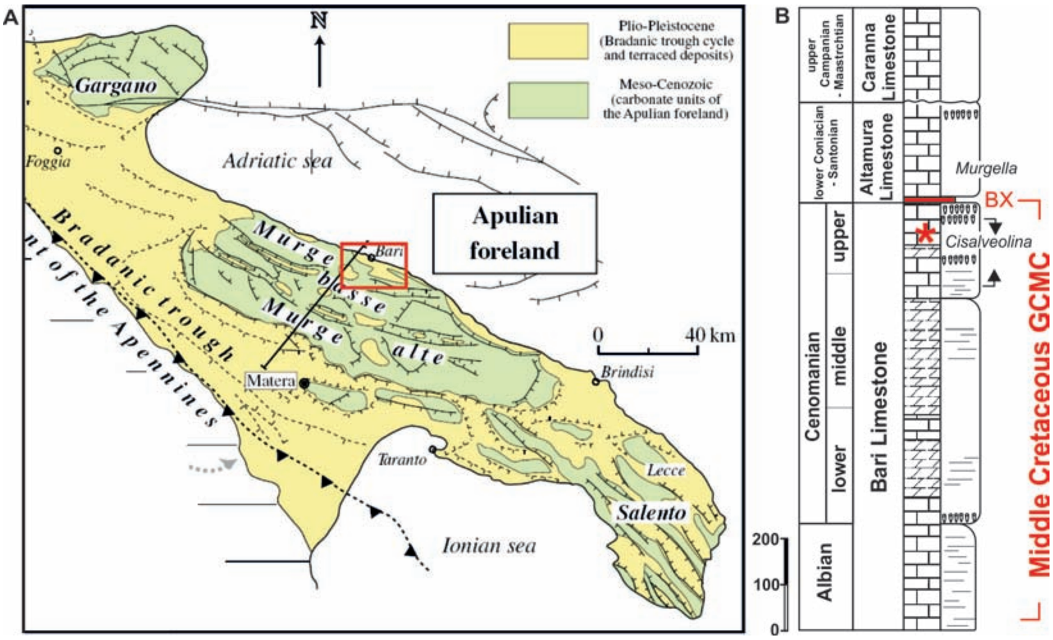

Fig. 5 - A: Geological map of Puglia region (from Spalluto, 2012). B: Column of the Albian-Maastrichtian deposits of Murge (simplified from Luperto Sinni and Reina, 1996; Spalluto, 2012). Asterisk indicates the position of the analyzed samples.

In the Salento sector (eastern Puglia) mostly Campanian and Maastrichtian carbonates crop-out. In this area, extensive studies of LBF, rudists and green algae have been carried out (De Castro, 1990; Parente, 1994, 1997; Cestari and Sartorio, 1995). Moreover, Strontium Isotope Stratigraphy has been applied successfully for understanding the vertical relationships of lithofacies (Schlüter et al., 2008). According to Bosellini et al. (1999) the following units have been recognised in thes area (Fig. 6).

a) Melissano Limestone. This is represented by peritidal limestones with rudists and LBF and is Turonian? to early Campanian (Schlüter et al., 2008).

b) Santa Cesarea Limestone. This is characterized by peritidal cycles with rare microbial laminites indicating supratidal phases. Rudist fragments are common. The age is middle Campanian (Schlüter et al., 2008).

c) Ciolo Limestone. This unit wasdeposited in a high energy setting and comprises grainstone and rudstone with rudist fragments and *Omphalocyclus*, *Siderolites*, *Orbitoides* and *Lepidorbitoides*. The age of the unit islate Campanian to Maastrichtian (Schlüter et al., 2008).

In this thesis LBF from Bari Limestone and Santa Cesarea Limestone have been studied. They belong to the Middle and Late Cretaceous GCMC, respectively.

Due to the monotony in facies types and subsequent difficulties in litostratigraphic classification, the LBF biozones of Chiocchini et al. (2001; 2012) and the scheme of Schlüter et al., (2008) are helpful in distinguishing the units. This biostratigraphy has been used in integration with updated chronostratigraphic charts (Steuber et al., 2005; Frijia et al., 2015).

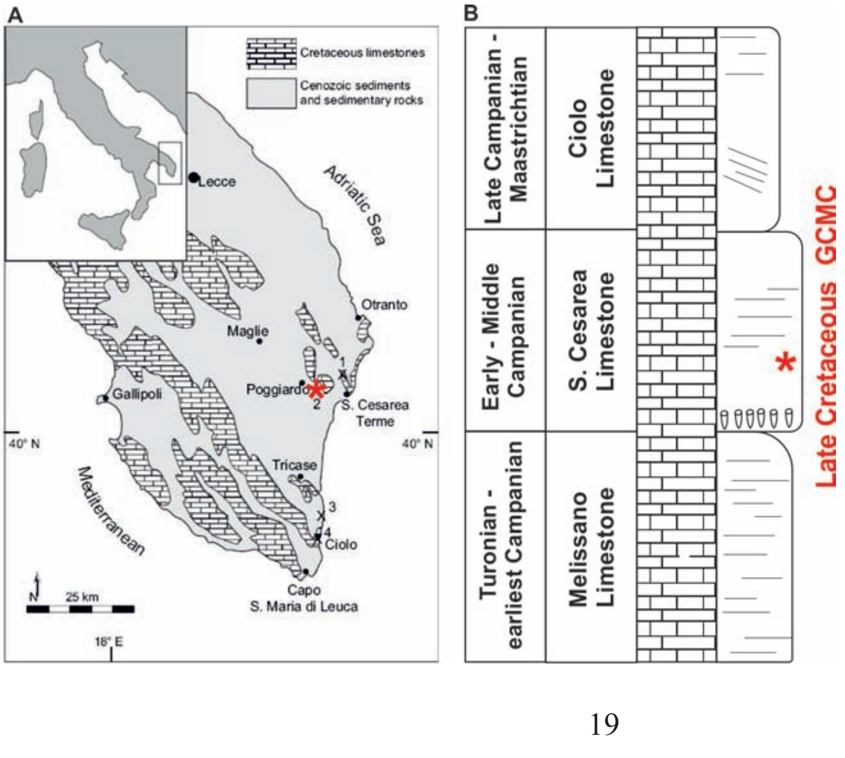

Fig. 6 - A: Geological map of the Salento. B: Lithostratigraphy of the Upper Cretaceous outcropping in Salento (not to scale). From Schlüter et al., (2008). Asterisk indicates the position of the studied sample.

2.4 Zagros Mountains

The Zagros Mountains are a NW-SE mountain chain located in SW Iran. The mountains extend from the Turkey and Iraq borders to the Strait of Hormuz and Makran Mountains for more than 1500 km in a belt 250 km wide. They constitute a morphological high between the Arabian Platform – Persian Gulf and Central Iran. The Zagros Mountains are generally divided into three parts: North-West (Lurestan), Central (Dezful Embayment) and South-East (Fars) sectors. The mountains resulted from the collision of the Arabian and Eurasian plates due to the closure of NeoTethys (Mouthereau et al., 2012).

Upper Cretaceous platform sediments cropping out in the Zagros Mountains were deposited in a broad continental ramp-like shelf. The same system also includes present-day Oman and the other Arabian platforms, which constituted the passive margin of the eastern African plate (Philip and Floquet, 2000; Vincent et al., 2015). In the complex geology of the Zagros Mountains the samples used in this thesis come from the northern and central areas, where the Albian-Turonian deposits are represented by the following units.

a) Kazhdumi Formation. This formation is characterized by limestone with orbitolinids and other Foraminifera like trocholinids and is Albian in age (Omidvar et al., 2014).

b) Sarvak Formation. This unit includes shallow-water deposits very rich in LBF and rudists and deep water deposits with planktonic Foraminifera dated as Albian–Turonian (Vahrenkamp, 2013; Omidvar et al., 2014, Vincent, 2015). The Sarvak Formation is generally divided into two subunits: lower and upper Sarvak Formation and the unit records the first tectonic stage involved during the early phase of the Alpine Orogeny. Within the Sarvak Formation an important unconformity can be identified in the CTB, which is represented in other areas of the world in Turonian deep-water facies.

In this thesis only the LBF present in the shallow-water facies of the Upper Sarvak Formation are studied. They are represented by a rich association of alveolinoideans, soritoideans, agglutinated foraminifera and some lamellar perforate foraminifera belonging to the Middle Cretaceous GCMC (Afghah and Dookh, 2014; Omidvar et al., 2014; Consorti et al., 2015).

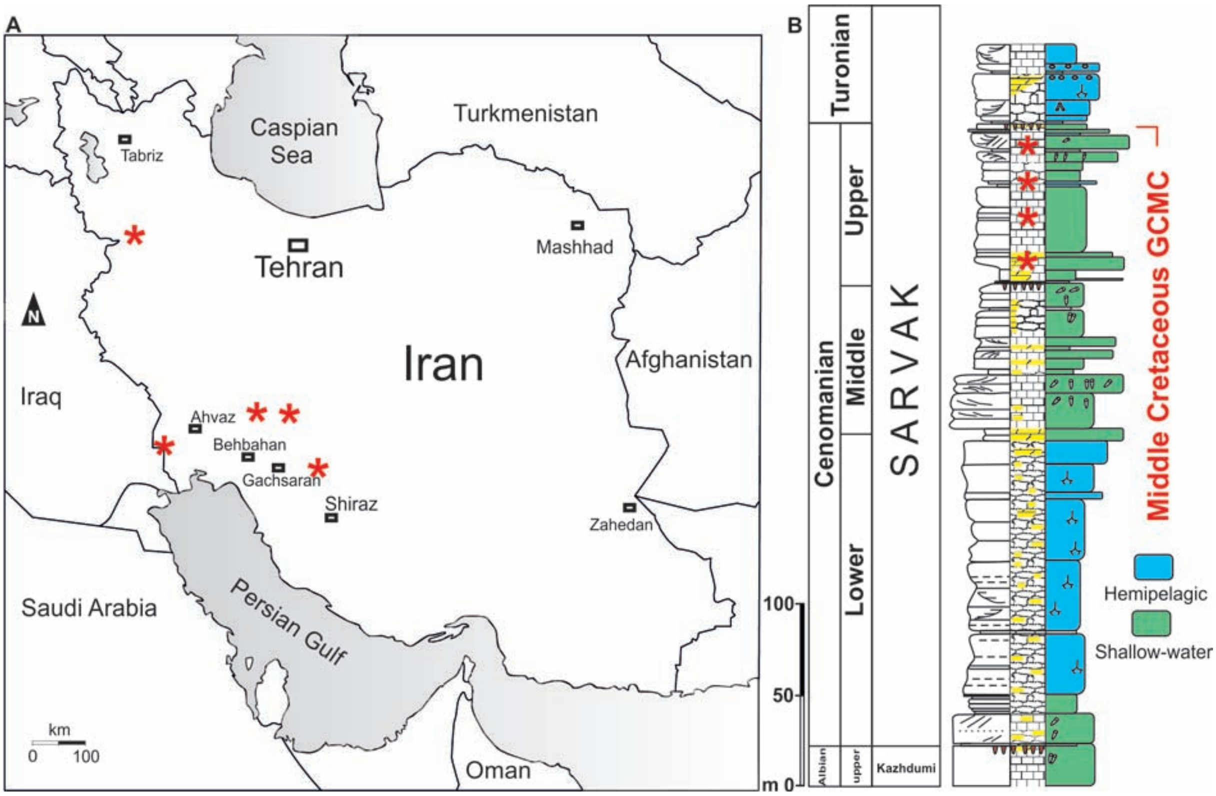

Fig. 7 - A: Map of Iran. B: Simplified geological column of the Chenareh Gorge (NW Zagros) taken from Frijia et al. (in prep.). Asterisks indicates the position of the samples studied in this thesis.

Chapter 3

MATERIAL AND METHODS

The Larger Benthic Foraminifera studied in this thesis come from 14 localities (see attached articles for their coordinates), which have been chosen for the particularities in the LBF content and stratigraphic position, constrained by biostratigraphy and/or chemostratigraphy (Strontium Isotope Stratigraphy, SIS, and Carbon and Oxygen isotope stratigraphy). 210 samples coming from these localities have been studied including samples collected by the author during the field-work in Italy and Spain and other material from the micropaleontology collections of the Universitat Autònoma de Barcelona and Alcalá de Henares (collection of A. Calonge) coming from previous research projects in which the members of the MicroPalaeontology Group were involved. Some samples from Italy were kindly furnished by Prof. Johannes Pignatti from 'La Sapienza' (University of Rome) and by Prof. Maurizio Chiocchini and Dr. Maria Rita Pichezzi from Roma (ISPRA collection). Dr. Gianluca Frijia (University Sultan Qaboos of Oman) also provided one additional sample from the southern Apennines. Some samples from Iran were collected by Dr. Ian Sharp from Statoil (Norway), whereas others came from the NIOC collection (National Iranian Oil Company). The collection 'Luperto Sinni', which comprises samples in thin-section from the Cretaceous of Puglia was visited during the XIV edition of SPI Congress 'Giornate di Paleontologia' (Bari, 11-13 June 2014). In all of the areas, the samples are represented by well cemented rocks, where the LBF can be studied only in sections.

In the laboratory, the samples were examined with a hand-lens in order to select the most appropriate area to cut thin-sections. A total of 460 standard (45mm x 27mm) and big (45mm x 57mm) thin-sections were prepared in the specialised laboratory of the Universitat Autònoma de Barcelona. LBF sections and microfacies have been photographed using a binocular microscope working with transmitted light (Leica Z16 APO). More than 3000 LBF pictures were taken, analysed and stored for this study. Frequently, samples rich in fossil content have been cut many times, sometimes producing more than forty thin-sections for each of them. This has allowed a great number of random sections to be used to build the architectural model of each studied LBF. Some samples have been carefully cut out and manually polished before the thin-sections were made (slabs also have been prepared to observe and photograph the large porcelaneous soritoideans). Thin section thickness varies due to the nature of the shell, this has been applied in solving problems of visibility (mainly refraction effects) in the architectural studies. For example, thin sections bearing rotaloideans (lamellar perforate shells) have been cut thicker (50-70µm) compared to those used to describe soritoideans (30-40µm).

The LBF sections have been studied to determine the nature of the shell, architecture and internal structure, and photographed. The pictures of LBF were enhanced with Photoshop software, printed and published at standard magnifications of x50 or x75 in order to facilitate comparison of specimens and taxa. In this thesis the general charatcers outlined by Hottinger (1978) were used to distinguish genera and species. Genera were identified by the presence or absence of structural elements combined with the chamber arrangement, while the species were defined by quantitative morphological characteristics.

All the material studied in this work was deposited in the Paleontology collection of the Department of Geology (Universitat Autònoma de Barcelona) and labelled as PUAB (see attached papers for reference to PUAB register numbers).

Samples for Strontium Isotope Stratigraphy (SIS) and Oxygen (O) and Carbon (C) isotope studies also were prepared. Strontium isotope stratigraphy has been applied in several levels in the Pyrenean sections (Montsec and Marginals Mountains) and in Central Italy on well-preserved specimens with pristine microstructure from rudist levels. C and O stratigraphy has been applied in Iran (Chenareh Gorge). Concentration of elements was determined with ICP-AES at the Geographisches Institut of the Ruhr-Universität of Bochum, whereas Strontium isotope analyses were performed at the Institute for Geology, Mineralogy and Geophysics of the Ruhr-University (Bochum, Germany).

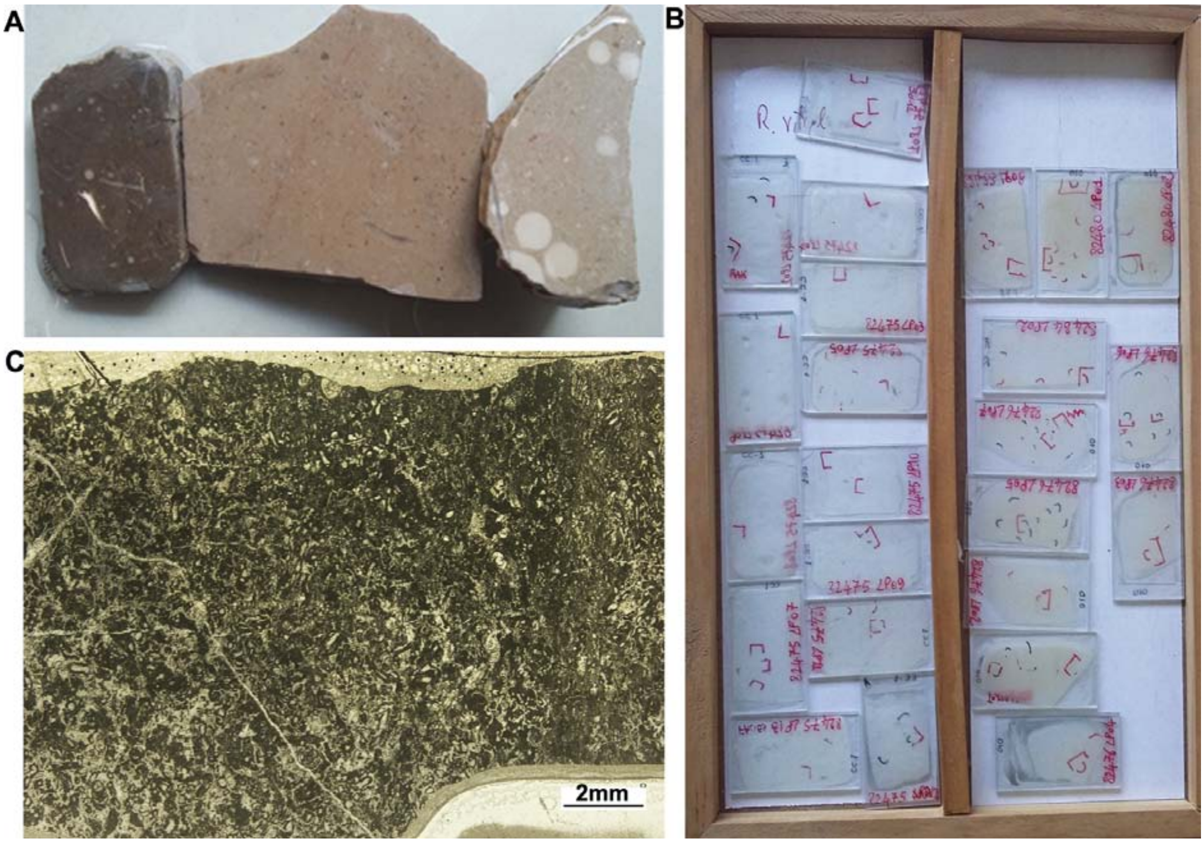

Fig. 8 - A: Polished slabs used in this study, note the presence of *Keramosphaerina* into the right slab. B: Thin sections collection management; each thin section studied and figured for publication has been labeled and stored in the Paleontology collection of the Department of Geology (Universitat Autònoma de Barcelona). C: Example of facies in thin section; cyanobacterial remains from the Campanian of Lepini Mounts.

Chapter 4

CONSTRAINS FOR THE MIDDLE CRETACEOUS GCMC

4.1 Overview

The late part of the Middle Cretaceous GCMC, which comprises the Cenomanian, is considered a period of high diversification in the evolution of LBF communities. This coincided with a generalized high sealevel (Haq, 2014) and elevated temperatures (Thomas and Tilghman, 2014), which allowed the development of wide platforms and the creation of new niches available for LBF.

During this period of time diverse groups of LBF lived in the shallowest environments such as alveolinoideans. For example, alveolinids and rhapydioninis developed endemic forms characterised by their big-size and very complex structures (septula, floors, pillars). In contrast, small morphotypes occupying diverse niches in the photic environments are more or less cosmopolitan.

Near the CTB a generalized extinction of LBF related with the Anoxic Oceanic Event 2 (AOE 2) took place (Caus et al., 1997; Parente et al., 2008; Arriaga et al., 2016) wiping out all the alveolinoideans (extreme K-strategists). Recently alveolinoideans have been extensively studied (Calonge et al., 2002; Vicedo et al., 2011; Piuzet al., 2014; Vicedo and Piuz, 2016), but no recent detailed study has been done on the other group of important Cenomanian large porcelaneous Foraminifera, the soritoideans, since the works of De Castro (1971), Hamaoui and Fourcade (1973), Cherchi et al. (1976) and Cherchi and Schroeder (1980). Moreover, the level of extinction of the k-strategist Cenomanian soritoideans in the CTB was controversial in Middle East areas. Therefore, the two following papers deal focus the Cenomanian soritoideans.

4.2 Article 1

Author's contribution

Praetaberina new genus (Type species: *Taberina bingistani* Henson, 1948): a stratigraphic marker for the Late Cenomanian

Journal: The Journal of Foraminiferal Research
Volume: 45
Pages: 378-389
Year of publication: 2015
Authors: Lorenzo Consorti, Esmeralda Caus, Gianluca Frijia, Mohsen Yagzi-Moghadam
Journal impact index (2015/2016): 1.589

PhD candidate contribution: L.C. participated in designing the hypothesis, and analyzed samples and thin sections, described components of the facies and the faunal content, collected bibliographical information, conducted the architectural analysis proposing differences between the two species described, wrote the manuscript and prepared figures.

Journal of Foraminiferal Research, v. 45, no. 4, p. 378–389, October 2015

PRAETABERINA NEW GENUS (TYPE SPECIES: *TABERINA BINGISTANI* HENSON, 1948): A STRATIGRAPHIC MARKER FOR THE LATE CENOMANIAN

Lorenzo Consorti[1,4], Esmeralda Caus[1], Gianluca Frijia[2] and Mohsen Yazdi-Moghadam[3]

ABSTRACT

A detailed architectural analysis has been performed on the porcelaneous species *Taberina bingistani* Henson, 1948 from diverse localities, including its type locality in Iran. Characterized by a subcylindrical to slightly conical shape, with a cribbed apertural face, the Cenomanian Middle-East species *bingistani* is removed from the American early-Paleogene genus *Taberina* Keijzer, 1945 (type species: *T. cubana*) and ascribed to the new genus *Praetaberina*. In the early stages of growth, the chambers are planispiral-involute, becoming uncoiled in the later stages. The interior of the chambers shows numerous septula and pillars. The septula are radial and distributed in the marginal area of the chamber lumen, while the pillars occupy the central area and are regularly distributed between the intercameral foramina. Pillars are in alignment from one chamber to the next. A new species, from southeast Italy, *Praetaberina apula*, is also erected. It differs from *P. bingistani* in its smaller size and significantly reduced structural elements. Both species characterize upper Cenomanian shallow-water deposits.

INTRODUCTION

Henson (1948), in his monograph on Mesozoic-Paleogene larger foraminifera of the Middle East, described a new species, *Taberina bingistani,* from Cenomanian deposits of the Kuh-e-Bingistan (Tang-e-Moghar, SW Iran). The species was described as “Test calcareous, imperforate, microgranular with very thin vitreous layer over the oral face of each chamber; chamber arrangement planispiral, involute in the young, later becoming serial and building a cylindrical, or acute conical, test with saucer shaped chambers; projected inward a short distance from, and at right angles to, the epidermis, there are numerous, thin, transverse sub-epidermal partitions normal to the septa; these partitions are in alignment from one chamber to the next, and are alternately long and short; they sometimes also show traces of thickening at their ends; in each chamber there are numerous intraseptal buttresses extending between roof and floor; as in *Coskinolina*; apertures cribrate, terminal” (p. 82).

Besides Iran, Henson (1948) reported *T. bingistani* from Iraq, Syria, and the former Palestine. In the following years, *T. bingistani* was also reported from several other localities of the Middle East, including Kuwait (El-Naggar & Al-Rifaiy, 1973), Lebanon (Saint-Marc, 1975), and Israel (Hamaoui, 1966), among others. Fleury (1980) reported *T. bingistani* from Greece, and more recently, Borghi & Pignatti (2006) mentioned “*Taberina*” *bingistani* in the Apulian platform carbonates (southeast Italy).

However, the Henson (1948) generic ascription of the Cenomanian Middle East species to the American Palaeocene genus *Taberina* (type species: *T. cubana* Keijzer, 1945) has been widely questioned (see for example: Whittaker et al., 1998; Borghi & Pignatti, 2006; Hottinger, 2007; Vicedo et al., 2013). Whittaker et al. (1998) attributed Henson’s species to the genus *Pseudorhapydionina* De Castro, 1972.

In the present paper, based on new material collected from several localities in Iran, including the type locality of *T. bingistani* Henson, the architecture of the controversial taxon is re-examined. The diagnostic taxonomic elements, detectable in thin-sections, necessitate the proposal of a new genus, *Praetaberina,* to include Henson’s species. Furthermore, we assess the stratigraphic distribution of the new genus using bio- and isotope stratigraphy.

Finally the study of the supplementary material from southern Italy, kindly provided by Prof. Johannes Pignatti (La Sapienza University, Roma), has enabled the introduction of the new species, *Praetaberina apula* n. gen., n. sp.

MATERIALS AND METHODS

The samples used for this work come from two regions: the Zagros Mountains in Iran and the Apulian platform in southern Italy (Fig. 1). In both areas, the samples are represented by well cemented carbonate rocks where the foraminifera can only be studied in thin-sections. No isolated specimens have been found in Iran or in Apulia.

In Iran, in excellent outcrops along the Chenareh Gorge (northwest of the Zagros Mountains), a 50 m-thick stratigraphic interval of shallow-water carbonate strata containing *Praetaberina bingistani* (Fig. 2) was sampled and analysed. This interval (which is described in detail for its sedimentological and geochemical features in a forthcoming paper by Frija et al., unpublished data) belongs to the Upper Sarvak Formation, and it is equivalent to the stratigraphic type-level of the so-called *Taberina bingistani* Henson. The studied interval consists of limestone with wackestone and packstone textures, and more rarely grainstone, which is rich in larger foraminifera, molluscs, echinoids and bryozoan debris (Fig. 3). Occasionally, its lower part shows a low-to-medium degree of dolomitization. The first 15 m are characterized by packstone with agglutinated and porcelaneous foraminifera, rudists and bryozoan bioclasts, associated with less abundant peloidal wackestone with fine bioclast debris. Upwards, the section becomes dominated by wackestone-packstone textures with benthic foraminifera and subordinated rudist bioclasts, intercalated at the top with rudist grainstone to rudstone. The ensemble is interpreted as deposited in a lagoonal setting.

The foraminiferal association, the distribution of which is shown in Figure 2, is composed of *Nezzazata* spp., *Coxites*

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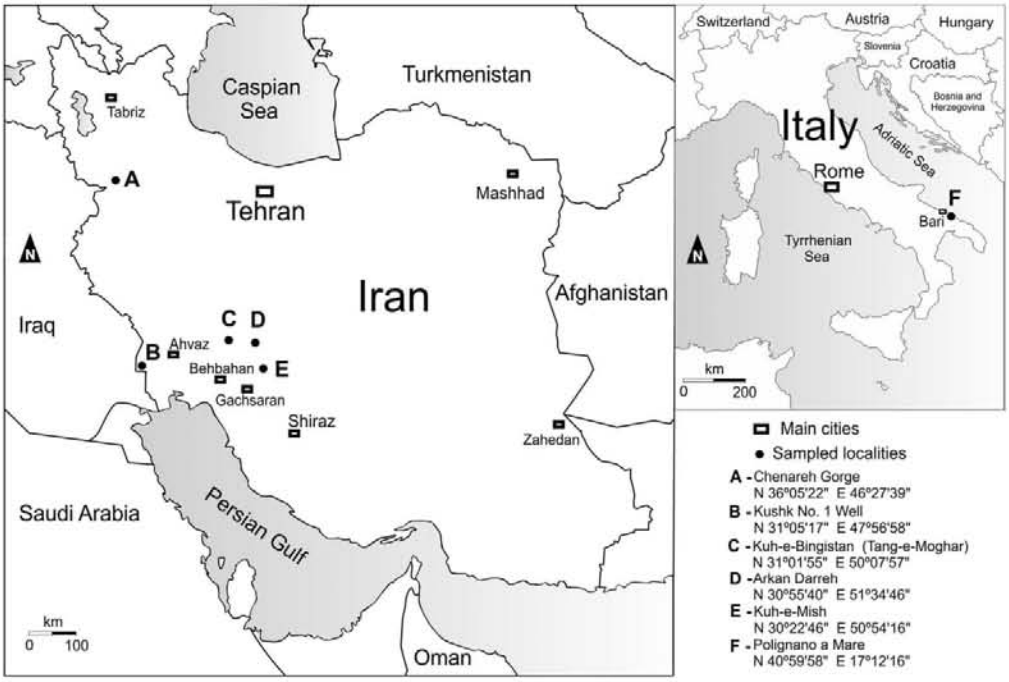

FIGURE 1. Locations of the studied samples.

zubairensis Smout, 1956, *Trochospira avnimelechi* Hamaoui & Saint-Marc, 1970, *Pseudolituonella reicheli* Marie, 1954, *Biplanata peneropliformis* Hamaoui & Saint-Marc, 1970, *Preaechrysalidina infracretacea* Luperto Sinni, 1979, *Dukhania conica* Henson, 1948, *Chrysalidina gradata* d'Orbigny, 1839, *Dicyclina sampoi* Cherchi & Schroeder, 1990, *Cisalveolina* cf. *lehneri* Reichel, 1941, *Cisalveolina fraasi* (Gümbel, 1872), *Decastroia* sp., *Pseudorhapydionina dubia* (De Castro, 1965), *Murgeina apula* (Luperto Sinni, 1968), and *Rotorbinella mesogeensis* (Tronchetti, 1981). A total of 21 samples (labelled WP95 to WP131) were collected from the Chenareh section (see sampled horizons in Fig. 2), and from these samples, 61 thin-sections were prepared. These contained more than 20 random sections of *Praetaberina bingistani*. Further samples from Iran (labelled NIOC-Ks, -Kb, -Ad, -Km), containing 12 well-preserved specimens of *Praetaberina bingistani*, come from the Central Zagros Mountains (see Fig. 1).

The Italian samples are from the upper part of the Calcare di Bari Formation (Bari Limestone Fm) and they have been collected near the village of Polignano (for details see Borghi & Pignatti, 2006). *Praetaberina apula* n. sp. comes from a thin level (5 cm) of grainstone with isopach cement around the grains (Fig. 3). Borghi et al. (1996) interpreted the facies containing *P. apula* as deposited in a peritidal environment. The associated foraminifera are *Trochospira avnimelechi*, *Biconcava bentori* Hamaoui & Saint-Marc, 1970, *Biplanata peneropliformis*, *Nezzazatinella picardi* (Henson, 1948), *Chrysalidina gradata*, *Pseudonummoloculina heimi* (Bonet, 1956), *Cisalveolina fraasi*, *Peneroplis parvus* De Castro, 1965, *Pseudorhapydionina dubia*, ?*Broeckina* sp., and *Rotorbinella mesogeensis*. From the Apulian platform outcrop, 28 thin-sections were prepared, yielding more than 35 random sections of *P. apula* n. sp.

The specimens figured in this paper are housed in the Paleontological Collection of the Universitat Autònoma de Barcelona, Spain, under the acronym PUAB numbers (82421–82425) and in the National Iranian Oil Company Collection in Iran (NIOC-Ks 01-03, -Kb 01, -Ad 01-02, -Km 01-04).

SYSTEMATIC MICROPALEONTOLOGY

Phylum FORAMINIFERA (d'Orbigny, 1826) emended Pawlowski et al., 2013
Class TUBOTHALAMEA Pawlowski, Holzmann & Tyszka, 2013
Order MILIOLINA (Delage & Hérouard, 1896) emended Pawlowski et al., 2013
Superfamily SORITOIDEA Ehrenberg, 1839
Family SORITIDAE Ehrenberg, 1839

Remarks. Currently, the Family Soritidae is commonly used as a basket for all complex porcelaneous foraminifera with a probable "peneroplid" origin. In the future, the whole family should be revised. The classification used for high level categories, such as phylum, class and order is from Pawlowski et al. (2013). For superfamily and family, Loeblich & Tappan (1987) is followed.

Subfamily "PRAERHAPYDIONININAE" Hamaoui & Fourcade, 1973

Remarks. Hamaoui & Fourcade (1973) conceived the Praerhapydioninae to encompass all cylindrical- to fan-shaped porcelaneous shells with a planispiral-involute chamber arrangement, becoming uncoiled or flabelliform

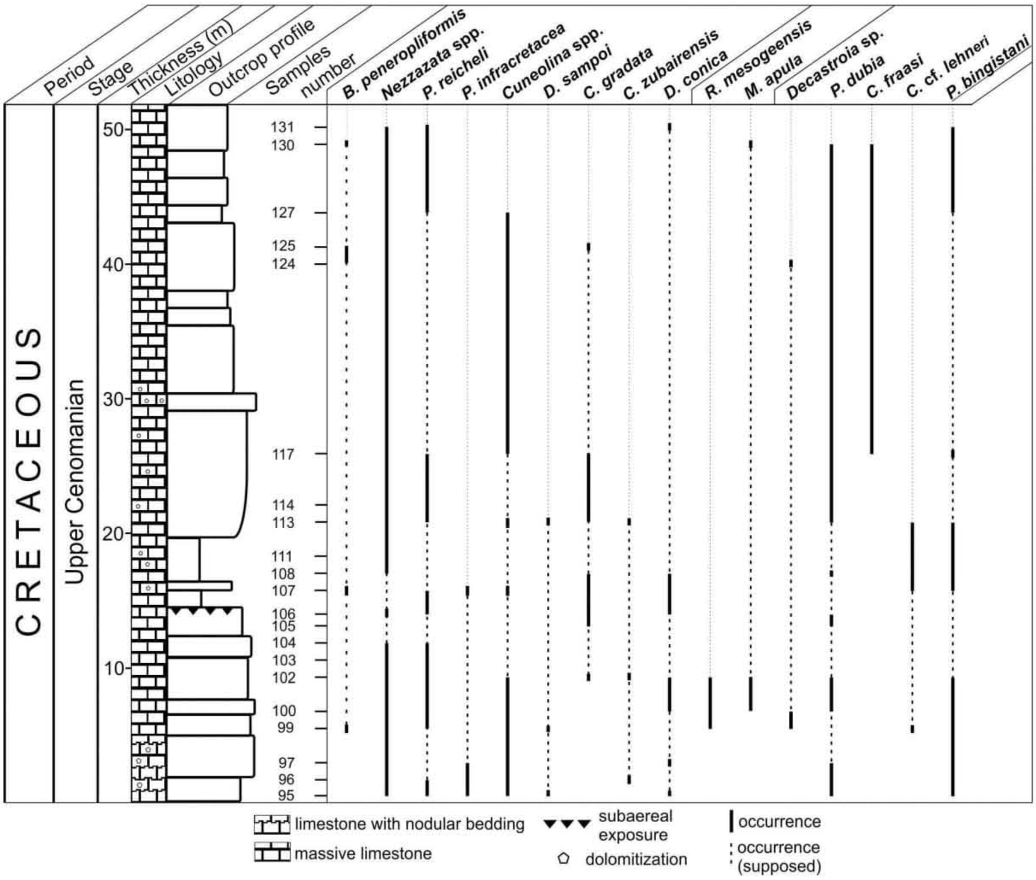

FIGURE 2. Stratigraphic interval containing *Praetaberina bingistani* in the Chenareh Gorge section. Note the distribution of the associated larger foraminiferal species.

to cyclical in adult stages. The apertural face is generally pierced by multiple openings (with the exception of the genus *Praerhapydionina* having only one stellate aperture). The marginal chamber lumen is partially subdivided by subepidermal plates, while the central area may or may not have pillars. The authors took the subfamily name from the genus *Praerhapydionina* Van Wessem, but designed *Taberina* Keijzer as the type genus of the subfamily, which is in disagreement with the International Code of Zoological Nomenclature (chapter 14). Therefore, the validity of this subfamily is questioned here and is in agreement with Fleury (1997). However, the production of a coherent suprageneric classification for all of Soritoidae is beyond the scope of this work.

The authors included in this subfamily *Taberina* and *Praerhapydionina* from the Paleogene Global Community Maturation (GCM) cycle (Hottinger, 1998, 2001), and others like *Edomia* Henson, 1948, *Cycledomia* Hamaoui, 1964, *Pseudorhapydionina* De Castro, 1971 and *Pseudorhipidionina* De Castro, 1971 from the Mid-Cretaceous GCM cycle. The new genus *Praetaberina* belongs to the Mid-Cretaceous cycle.

Loeblich & Tappan (1987) added to the subfamily Praerhapydionininae Hamaoui & Fourcade the following new genera: *Globoreticulina* Rahaghi, 1978, *Lamarmorella* Cerchi & Schroeder, 1975, *Murgella* Luperto Sinni, 1965 and *Scandonea* De Castro, 1971. However, from our point of view these last genera do not share the diagnostic features mentioned by Hamaoui & Fourcade (1973) for the subfamily Praerhapydioninae. *Globoreticulina* is an early Paleogene alveolinid with an exoskeleton formed by numerous rows of alveoli, and has been transferred to the Malatyninae subfamily (see Hottinger, 2007). Among the Late Cretaceous GCM cycle, the Sardinian genus *Lamarmorella* has a simple endoskeleton similar to the genus *Broeckina* Munier-Chalmas, 1882 (see the revision of the genus in Caus et al., 2013) while *Murgella* and *Scandonea* show a basal layer and their nepionts have milioliform signatures (see Luperto Sinni, 1965, and De Castro, 1971, respectively).

Genus *Praetaberina* nov.

Type species: *Taberina bingistani* Henson, 1948

Etymology. In allusion to the age of the new genus and the architectural analogy to the Paleogene genus *Taberina*.

Diagnosis. Moderately large porcelaneous tests with subglobular morphology in its early stage and subcylindrical to slightly flared conical in late stage. The

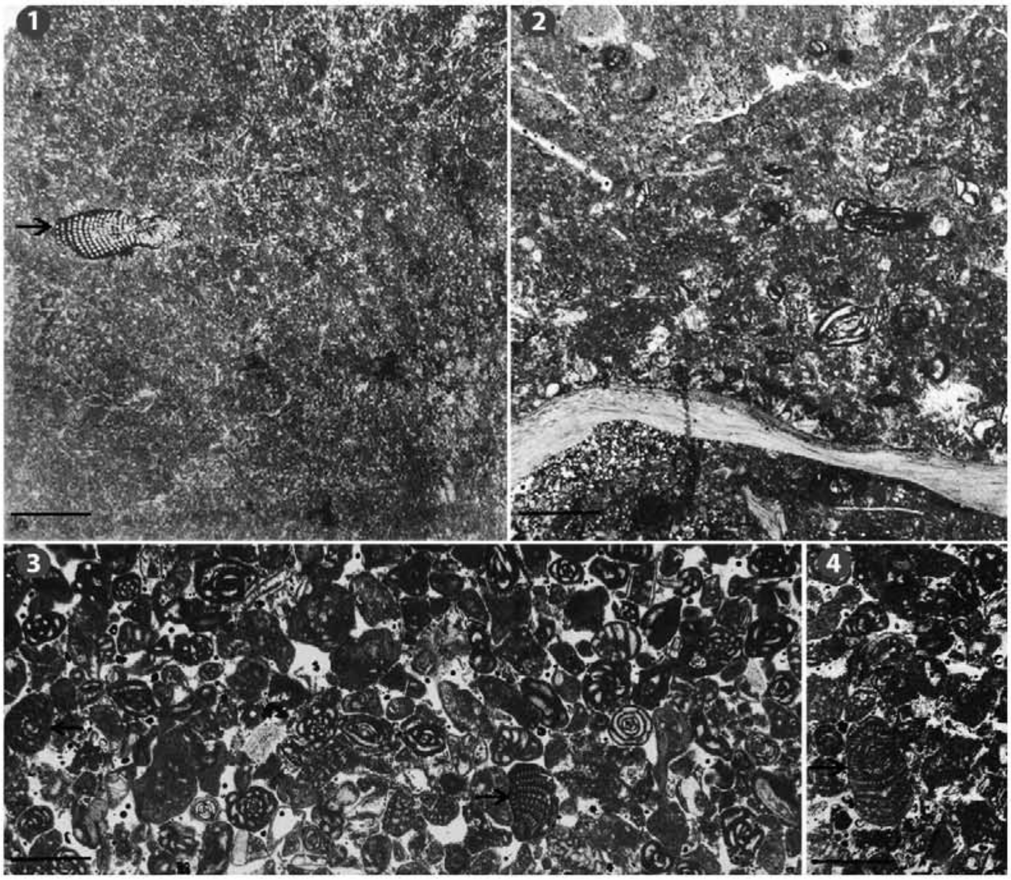

FIGURE 3. Microphotographs of *Praetaberina*-bearing facies. Scale bar 1 mm. **1** Slightly dolomitized micropeloidal wackestone; Chenareh Gorge. **2** Foraminiferal wackestone, fragments of bivalve shells are also present; Chenareh Gorge. **3, 4** Foraminiferal grainstone of the thin *P. apula* level; note the presence of intraclasts and small micritized grains; arrows indicate the position of *Praetaberina* in the microfacies; Polignano a Mare.

apertural face is cribbed with numerous rounded openings. In the early stage of growth, the chambers are in a planispiral-involute arrangement, but in the later stage they become uncoiled (Fig. 4). The marginal area of the chamber lumen is partially subdivided by numerous thin, radial septula ("subepidermal partitions" in Henson, 1948 and Fleury, 1996; "septula" in Hottinger, 2007 and this work), at least of two orders, placed at right angles to both the external wall and the septa. The septula are commonly aligned from one chamber to the next, although the regularity is partially lost during growth when new elements are added. The inner end of the main septula merges with the outermost row of pillars. The central area of the chambers is occupied by pillars ("intraseptal buttresses" in Henson, 1948), which are commonly aligned from one chamber to the next. The intercameral foramina are regularly distributed between the pillars and the distal part of the main septula. The foraminal axes follow a radial pattern and are aligned in consecutive chambers.

Differential diagnosis. Praetaberina n. gen. can be easily distinguished from the other Cenomanian genera included in the "Praerhapydionininae", with which it is frequently associated. *Pseudorhapydionina* (type species: *Rhapydionina laurinensis* De Castro, 1965) and *Pseudorhipidionina* (species type: *Rhipidionina casertana* De Castro, 1965) lack pillars (for more information about these two genera see De Castro descriptions in Schroeder & Neumann, 1985). *Cycledomia* Hamaoui (type species: *Edomia iranica* Henson, 1948) has similar structural elements to *Praetaberina,* but it develops a planispiral to flabelliform mode of growth in the early stages of growth, becoming annular in adult stage (see pl.1, figs. 1–4; pl. 2, figs. 4–8 in Hamaoui, 1964). According to Reiss et al. (1964), the specimens attributed to *Edomia* (type species: *E. reicheli* Henson, 1948) by Henson (pl. 8, figs. 1–14, 1948) have a planispiral-involute arrangement of the chambers throughout ontogeny, and pillars less developed than in *Praetaberina* n. gen. From Iraq, Mohammed (2006) described the new genus *Bicyclina* with an architecture closely related to *Cycledomia*, but with "two distinct sets of subepidermal partitions" as it is figured in Hamaoui (1964, pl. 2, fig. 15, gen. aff. *Cycledomia* sp.).

Praetaberina n. gen. differs from the Paleogene genus *Taberina* (species type: *T. cubana*) in having a more complex internal structure. The former genus shows two orders of marginal partitions and apertures alternating with the main septula, while *Taberina* lacks such intercalate apertures (for

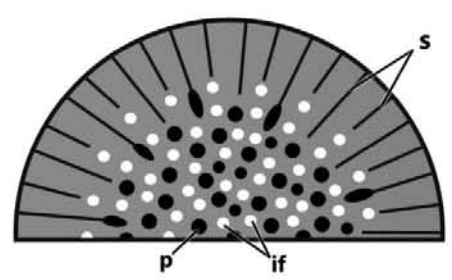

FIGURE 4. Structural pattern in *Preaetaberina* n. gen. The half cylinder is referred to a perfect transversal section of the uncoiled stage of growth. Schematic, not to scale. To be compared with the genus *Neotaberina* in Hottinger (2007, fig. 2C). if: Intercameral foramina, p: pillar, sl: septulum

comparison, see fig. 4 in Vicedo et al., 2013); moreover, the last genus has the pillars with a patchy distribution. Moreover, *Praerhapydionina* (species type: *P. cubana*) is clearly distinguishable from *Praetaberina* by its spiroliniform morphology and only one stellar aperture. The Paleogene genera *Rhabdorites* Fleury, 1996 (type species: *Rhapydionina malatyaensis* Sirel, 1976) and *Neorhipydionina* Hottinger, 2007 (type species: *Rhipidionina wiliamsoni* Henson, 1948) are homeomorphs with the Cenomanian genera *Pseudorhapydionina* and *Pseudorhipidionina*, respectively.

The architectural pattern of *Praetaberina* is similar to *Neotaberina* Hottinger, 2007 (type species: *N. neaniconica*, 2007), but the spatial relationship between radial septula and intercameral foramina presents some differences: *Praetaberina* has only one, or exceptionally two, rows of apertures between the main radial septula, while *Neotaberina* has several rows extending almost to the periphery of the chamber and the pillared zone overlaps with the distal endings of the septula (see fig. 2 in Hottinger, 2007, for comparison). Furthermore, *Neotaberina* has a poorly developed spiral stage compared with *Praetaberina*.

Praetaberina bingistani (Henson, 1948)
Figs. 5–7

Taberina bingistani Henson, 1948, pl. 6, figs. 4–6.

Taberina bingistani Henson. Hamaoui, 1966, pl. 8, fig. 6.

Taberina bingistani Henson. Sampò, 1969, pl. 42, figs. 20–22; pl. 43, fig. 12.

Taberina bingistani Henson. Saint-Marc, 1975, pl. 7, figs 1–10.

cf. *Pseudorhapydionina laurinensis* (De Castro). Kuss & Malchus, 1987, p. 905, text-fig. 32.

Pseudorhapydionina bingistani (Henson). Whittaker et al., 1998, pl. 98, fig. 4–6.

Taberina bingistani Henson. Boudagher-Fadel, 2008, pl. 5.16, figs. 7–8.

indeterminate foraminifera, Ghabeishavi et al., 2010, p 281, fig. 9E.

Daxia cenomana Cuviller & Szakall. Afghah et al., 2014, fig. 8B.

Taberina bingistani Henson. Afghah & Fadaei, 2014, fig. 8f (error: fig. 8 and 9 are inverted).

Remarks. In this paper, we have added only a few notes to Henson's original description. All the centered specimens at our disposal are A-forms. The measured megalospheres show a diameter of ~100–120 µm. Only a few large oblique sections could be B-forms. In the megalospheric generation, the planispiral-involute chambers following the megalosphere are arranged into two and a half to three whorls, with a diameter of 0.7–1 mm. The number of chambers is ~8–10 in the first whorl, ~15–20 in the second whorl, and >30 in the third whorl. In the uncoiled stage of growth, the number of chambers is 10–13 in the small, cylindrical specimens (A-forms), and up to 15 in the large, slightly conical specimens (B-forms?). The height of the uncoiled stage varies from 0.7–2.1 mm. The marginal area of the chamber lumen is subdivided by radial septula of roughly two orders, with the number per quadrant ~15 in a radius of 0.35 mm. They occupy only about one-quarter of the total chamber lumen. The central part of the chamber lumen has pillars, which are inverted truncate cones in shape. At the roof, the pillars can merge laterally.

Comments on shell texture. As has already been pointed out by Henson (1948), a thin 'vitreous' layer is recognizable on the septal face of the Iranian specimens (see for instance Figs. 5.1, 5.4, 7.3, 7.4). Under high magnification on a petrographic microscope, this layer shows fine calcite crystals oriented chaotically, suggesting a diagenetic modification of the original wall microstructure.

Geographic occurrence. Praetaberina bingistani is known from several localities in the Middle East: Iran, Iraq, Oman, Syria, Lebanon, Israel, and probably Egypt and Somalia.

Associated fauna. Nezzazata simplex Omara, 1956, *N. conica* (Smout, 1956), *N. gyra* (Smout, 1956), *Coxites zubarensis*, *Trochospira avnimelechi*, *Biconcava bentori*, *Pseudolituonella reicheli*, *Preaechrysalidina infracretacea*, *Dukhania conica*, *Chrysalidina gradata*, *Dicyclina sampoi*, *Cisalveolina fraasi*, *Decastroia* sp., *Pseudorhapydionina dubia*, *Cycledomia iranica*, *Sellialveolina drorimensis* (Reiss, Hamaoui & Ecker, 1964), *Edomia reicheli*, *Murgeina apula*, *Rotorbinella mesogeensis*, miliolids, textularids, and very rare trocholinids.

Age. Late Cenomanian

Praetaberina apula n. sp.
Fig. 8

Taberina bingistani Henson. Fleury, 1980, pl. 1, figs. 7, 8, 10.

"*Taberina*" *bingistani* Henson. Borghi & Pignatti, 2006, p. 90, 91, figs. 3–5.

Holotype. fig. 8.4 (PUAB 82421 LP04.01)

Etymology. From Puglia (Apulia in Latin), southeast Italy

Locality-type. Polignano a Mare. Coordinates: 40°59′58"N– 17°12′16"E

Type level. Upper part of the Bari Formation, Upper Cenomanian

Description. Porcelaneous, subcylindrical test with a multiple, cribbed, terminal aperture. The megalosphere has a diameter of ~80 µm. The earlier stages of growth, with a diameter of 0.7 mm, are generally constituted by two and half whorls of planispiral-involute chambers with 6–7 chambers in the first whorl and ~13 in the second whorl. The average number of chambers in the adult uncoiled stage is ~7–9, with a maximum of 13 in the largest specimens. The height of the uncoiled stage varies from 0.7–0.9 mm (up to 2 mm the specimen figured by Borghi & Pignatti, 2006). The number of radial septula per quadrant

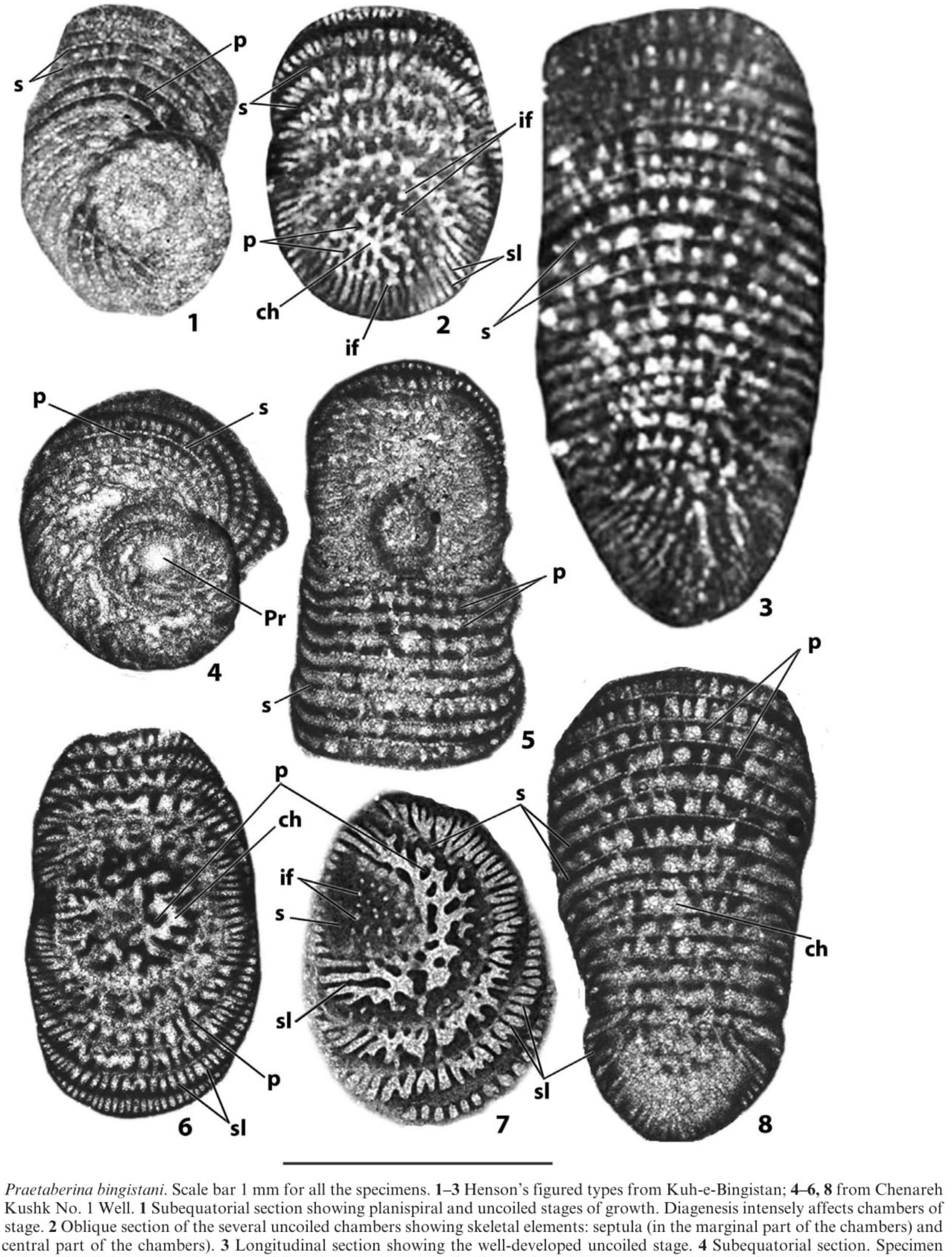

FIGURE 5. *Praetaberina bingistani*. Scale bar 1 mm for all the specimens. **1–3** Henson's figured types from Kuh-e-Bingistan; **4–6, 8** from Chenareh Gorge; **7** from Kushk No. 1 Well. **1** Subequatorial section showing planispiral and uncoiled stages of growth. Diagenesis intensely affects chambers of the planispiral stage. **2** Oblique section of the several uncoiled chambers showing skeletal elements: septula (in the marginal part of the chambers) and pillars (in the central part of the chambers). **3** Longitudinal section showing the well-developed uncoiled stage. **4** Subequatorial section. Specimen partially dissolved (PUAB 82424 LP01.01). **5** Sub-axial section of a test partially dissolved cutting two whorls of the planispiral stage (PUAB 82423 LP02.01). **6** Tangential, slightly oblique section. Radial septula and merged pillars are visible (PUAB 82424 LP01.02). **7** Oblique section showing the skeletal elements of the successive chambers. Note the position of the foramina in the septum in the left side (NIOC Ks-01). **8** Longitudinal section showing the well-developed uncoiled stage (PUAB 82423 LP02.02). Pr: proloculus; ch: chamber; p: pillar; s: septum; sl: septulum; if: intercameral foramen.

is ~7–8 in a radius of 0.25 mm, and they occupy half of the chamber lumen but, in view of the micritization of our specimens, this value is probably an overstatement. The pillars are cylindrical in shape.

Differential diagnosis. The megalospheres and the adult specimens of *P. apula* are smaller than those of *P. bingistani*. *Praetaberina apula* commonly has two spiral-involute whorls with a maximum of two and half, while *P. bingistani* commonly has two and half, with a maximum of three. The number of septula per quadrant is much reduced in *P. apula* compared with *P. bingistani*. The radial septula occupy half of the chamber lumen in *P. apula*, whereas in *P. bingistani* they occupy only one-quarter. Therefore, the central space of the chamber, available to be occupied by the apertures and pillars, is larger in *P. bingistani* than in *P. apula.* The pillars are truncate-cone shaped in P. *bingistani*, and cylindrical in *P. apula*.

Geographic occurrence. So far *P. apula n. sp.* is known from its type locality and from Greece (Proti Island, Fleury, 1980).

Associated fauna. Trochospira avnimelechi, *Biconcava bentori*, *Biplanata peneropliformis*, *Nezzazatinella picardi*, *Chrysalidina gradata*, *Pseudonummoloculina heimi*, *Cisalveolina fraasi, Peneroplis parvus* De Castro, 1965, *Pseudorhapydionina dubia*, *Broeckina* sp., *Rotorbinella mesogeensis*, miliolids, and some textularids.

Age. Late Cenomanian

DISCUSSION OF THE AGE OF *PRAETABERINA*

The age of the Cenomanian platform sediments, and in general of Cretaceous shallow-water deposits where ammonites, planktonic foraminifera or calcareous nannoplankton are scarce or absent, derives mainly from the large benthic foraminifera. Several tentative zonations and chart ranges have been published (e.g., Schroeder & Neumann, 1985; Chiocchini et al., 1994, 2012; Whittaker et al., 1998; Velić, 2007). However, the lack of direct correlation with coeval pelagic deposits strongly hampers the possibility to tie the ranges of larger foraminifera to the chronostratigraphy. This problem becomes even more complicated if considering the frequent revisions of the stage boundary ages or divisions (early, middle and late) within the stages through successive global time-scales (e.g., Harland et al., 1989; Gradstein et al., 2004, 2012; Ogg et al., 2008).

In the present work, we have tried to overcome these shortcomings by establishing the range of *Praetaberina* using biostratigraphy (considering mutual control between the species of the associated other larger foraminifera with *Praetaberina* species, and whenever possible, correlating the deposits containing *Praetaberina* with planktonic foraminiferal zones) together with chemostratigraphic data.

Both the Iranian and Italian species appear together with *Cisalveolina fraasi,* which is a good marker for the upper Cenomanian deposits (De Castro, 1983; Parente et al., 2008; Frijia et al., 2015), suggesting a late Cenomanian age for *Praetaberina*. However, in the Chenareh Gorge section, the presence of *C.* cf. *lehneri* and the lack of *C. fraasi* in the lower part of the *Praetaberina* interval would not permit, based on larger foraminiferal distribution, excluding a middle Cenomanian age. In some sections of the Anaran anticline (southwest Iran), *P. bingistani* has been found in the same samples as *Sellialveolina drorimensis*, which is also ascribed to the late Cenomanian (Reiss et al., 1964; Smith et al., 1990; Vicedo et al., 2011). Furthermore, in this last area, the shallow-water deposits containing *P. bingistani* overly hemipelagic strata with planktonic foraminifera from the *Rotalipora cushmani* zone (middle and late Cenomanian according to Premoli Silva & Slitter, 2002).

Concerning previous works about the age of the *Praetaberina bingistani*, very few studies reported this species from deposits older than upper Cenomanian. Furthermore, the attribution of the reported specimens to *P. bingistani* is poorly figured and very doubtful. Saint-Marc (1975) indicates *Praetaberina bingistani* from the lower to upper Cenomanian of Lebanon, although the only figured *Praetaberina* in his work (pl. 7, figs. 1–10), come from the upper Cenomanian deposits. Fourcade et al. (1997) mentioned *Taberina bingistani* in the Sarvak Formation (Tang-é-Ghili) associated with *Multispirina iranensis* Reichel, 1947, also suggesting a late Cenomanian age. Recently, two biostratigraphic revisions of the Sarvak succession in the SW of the Zagros Mountains (Afghah et al., 2014 and Afghah & Fadaei, 2014) support a late Cenomanian age. Afghah et al. (2014) figured, under the name of *Daxia cenomana* (see the synonym list), *P. bingistani* from the upper Cenomanian of the Samghan section. Afghah & Fadaei (2014) showed the occurrence of *P. bingistani* in several levels of the upper Cenomanian of the Bavan section (see foraminiferal distribution in fig. 3), while only one sample containing *P. bingistani* from the Kharameh section was attributed to the lower Cenomanian (see foraminiferal distribution in fig. 4).

Chemostratigraphic correlation of the shallow-water carbonates of the Chenareh Gorge with the actual reference curve of carbon isotopic variation through the Cenomanian-Santonian stages (Jarvis et al., 2006) allows high-resolution dating of the studied Iranian deposits with reference to the chronostratigraphic framework established by those authors. Significant $\delta^{13}C$ inflection points, thought to be not diagenetic or local artifacts, are used to correlate the Chenareh isotopic record with the standard reference curve, and to constrain the range of *Praetaberina bingistani*. The first occurrence of *P. bingistani* occurs in the upper part of a marked $\delta^{13}C$ positive shift, which can be correlated with the mid-Cenomanian events I and II of Jarvis et al. (2006), with the most prominent positive excursions before the Cenomanian/Turonian boundary $\delta^{13}C$ event. According to our chemostratigraphic correlations, the first appearance of *P. bingistani* can be dated as very early late Cenomanian, near the boundary between middle and late Cenomanian, whereas its last occurrence is found in the upper Cenomanian. However, the species is not present in the uppermost Cenomanian levels of Chenareh Gorge section, suggesting that the range of *P. bingistani* is confined to the lower and middle part of the upper Cenomanian (Frijia et al., unpublished data).

Finally, we would like to highlight that a Turonian age attributed to *Praetaberina bingistani* in some regional studies (Razin et al., 2010; Al-Dulaimy & Al-Sheikhly, 2013, among others), on the basis of the presented data, is not consistent. Our data therefore further support the evidence that all larger foraminifera from the middle GCM

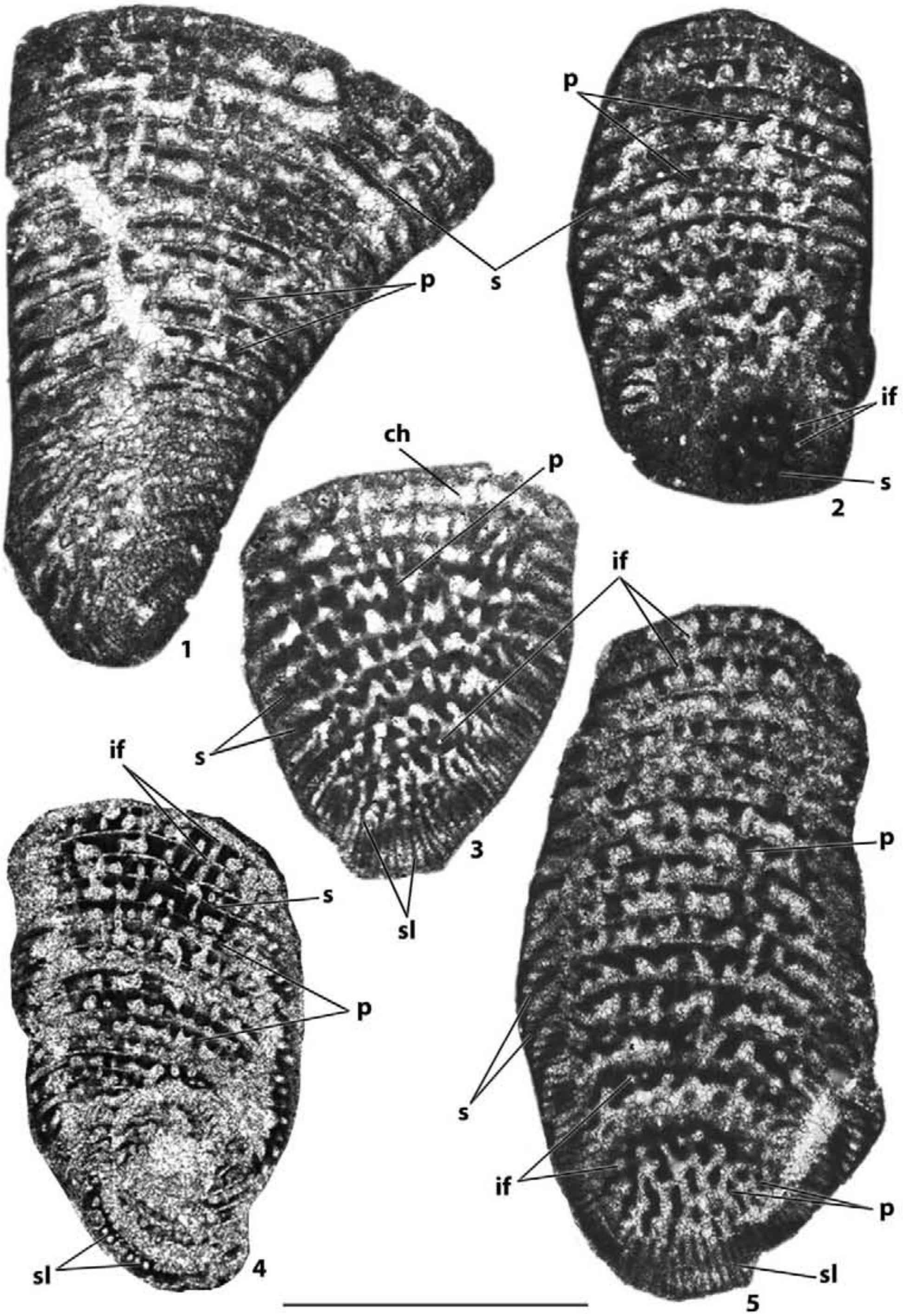

FIGURE 6. *Praetaberina bingistani*. Scale bar 1 mm for all specimens. Specimens **1–3, 5** are from Chenareh Gorge; **4** Specimen from Kushk No. 1 Well. **1** Longitudinal slightly-oblique section of the uncoiled stage (PUAB 82424 LP02.03). **2** Longitudinal section showing the planispiral and uncoiled stage. In the planispiral part, which is tangentially sectioned, the intercameral cribrate foramina are well visible (PUAB 82425 LP01.01). **3** Tangential oblique section (PUAB 82423 LP01.01). **4** Oblique section showing spiral to uncoiled chambers. Note the peripheral position of the radial septula in the chamber. The pillars occupy its central part. The specimen is partially dissolved (NIOC Ks-02). **5** Longitudinal section. Note the septa traversed by the intercameral foramina and the position of the pillars (PUAB 82422 LP01.01). ch: chamber; p: pillar; s: septum; sl: septulum; if: intercameral foramen.

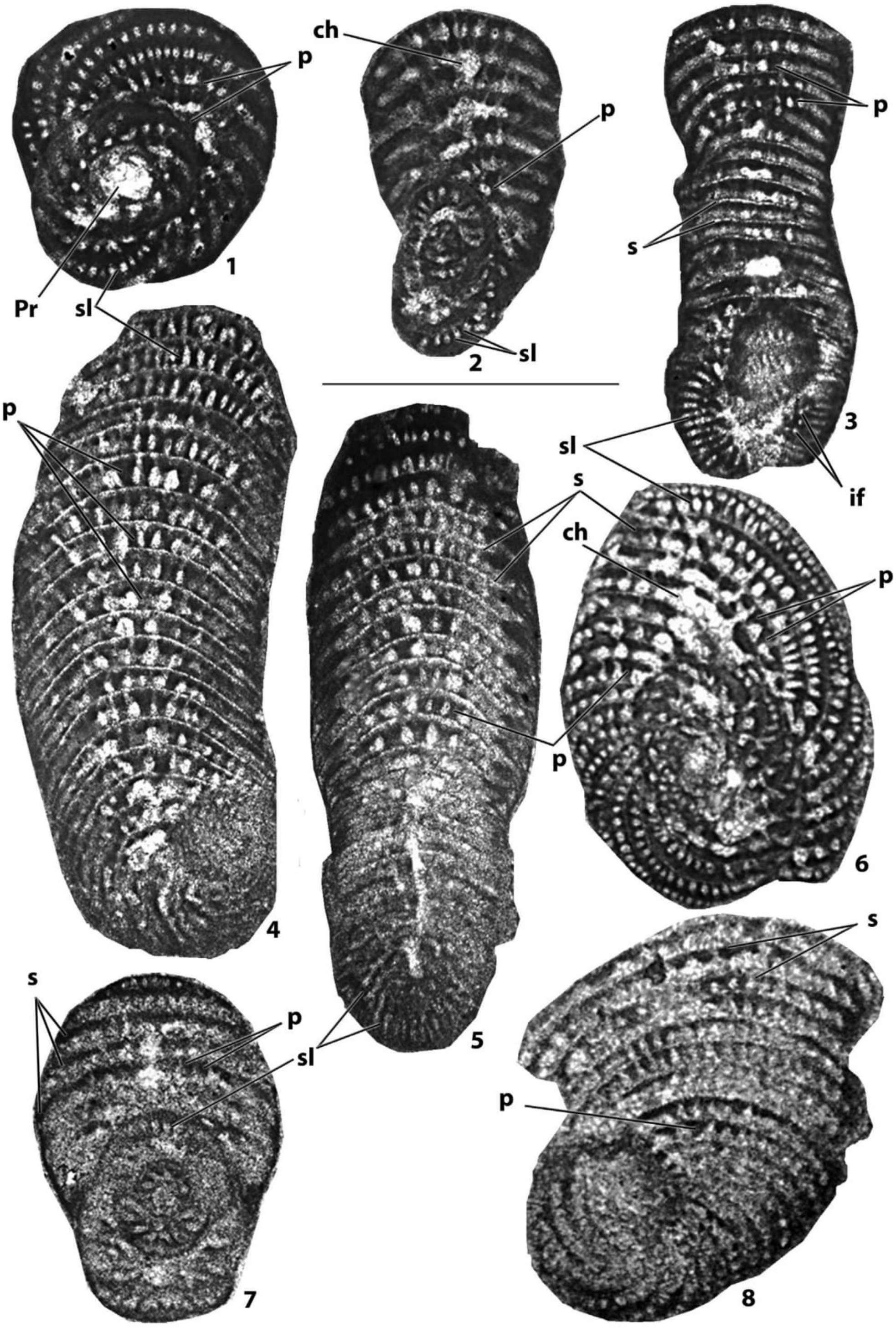

FIGURE 7. *Praetaberina bingistani*. Scale bar 1 mm for all specimens. **1** from Kuh-e-Bingistan; **2, 7** from Arkan Darreh; **3, 4, 5, 8** from Kuh-e-Mish; **6** from Kushk No. 1 Well. **1** Centered oblique section near the equatorial section (NIOC Kb-01). **2** Sub-axial, slightly oblique section showing internal planispiral whorls (NIOC Ad-01). **3** Sub-axial section. Note the outermost row of foramina intercalated with the septula (NIOC Km-01). **4, 5** Longitudinal sections (NIOC Km-02, NIOC Km-03). **6** Centered slightly oblique section showing the radial septula and the pillars (NIOC Ks-03). **7** Sub-axial section appearing highly diagenetically altered (NIOC Ad-02). **8** Partly recrystallized sub-equatorial section (NIOC Km-04). ch: chamber; p: pillar; s: septum; sl: septulum; if: intercameral foramen; Pr: proloculus.

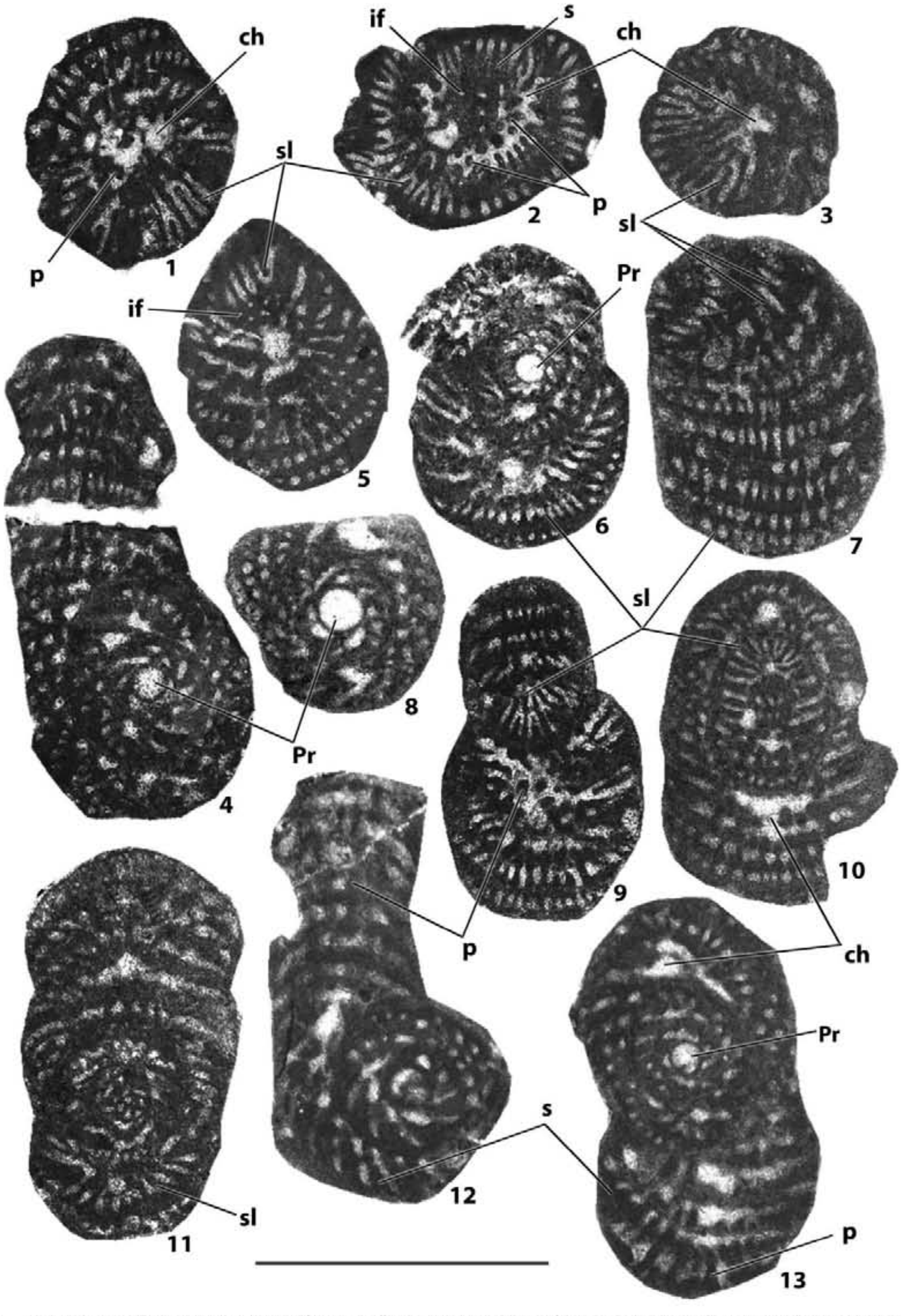

FIGURE 8. *Praetaberina apula* n. sp. Scale bar 1mm for all specimens. All the specimens from Polignano a Mare. **1, 3, 5** Oblique sections (PUAB 82421 LP01.01, PUAB 82421 LP02.01, PUAB 82421 LP02.02 respectively). **2** Transverse section showing septa pierced by foramina, the pillars and the radial sepula (PUAB 82421 LP07.01). **4, 8** Oblique-centered section nearest to the equatorial section broken in the upper part (PUAB 82421 LP04.01, PUAB 82421 LP08.01). **6** Axial slightly oblique section (PUAB 82421 LP02.03). **7** Tangential section (PUAB 82421 LP06.01). **9** Sub-axial section showing radial septula in the marginal part of the chamber and pillar in the central part (PUAB 82421 LP05.01). **10** Similar to 9, cutting tangentially the first two and a half whorls (PUAB 82421 LP02.04). **11** Sub-axial, slightly oblique section (PUAB 82421 LP09.01). **12** Sub-equatorial section (PUAB 82421 LP03.01). **13** Oblique centered section showing the pillar (PUAB 82421 LP03.02). ch: chamber; p: pillar; s: septum; sl: septulum; if: intercameral foramen; Pr: proloculus.

cycle disappear before the Cenomanian-Turonian Boundary Event (Caus et al., 1993, 1997; Calonge et al., 2002; Hart et al., 2005; Parente et al., 2008, among others).

CONCLUSION

New material from several localities in Iran has allowed us to revise the controversial taxon *Taberina bingistani* Henson, 1948. The accurate architectural study indicates that the species *bingistani* cannot be ascribed to the American Palaeocene genus *Taberina*, or even to any other described genus. Therefore, the new genus *Praetaberina* (type species: *Taberina bingistani* Henson) is described in this work. *Praetaberina* is characterized by its planispiral-involute to uncoiled arrangement of the chambers, a skeleton constituted by septula and pillars, and multiple foramina regularly distributed between the pillars and one row alternating with the longest radial septula. The intercameral foramina are aligned in consecutive chambers.

Two species are ascribed to the new genus: *P. bingistani* (Henson), common in the Middle East deposits, and *P. apula* n. sp. described from southeast Italy and Greece. This last species differs from *P. bingistani* by the smaller size of their megalospheres and adult specimens, and less complexity of the internal skeleton elements. The age attributed to the genus *Praetaberina,* based upon biostratigraphic and chemostratigraphic data, is late Cenomanian. Finally, *Praetaberina* occurs in shallow-water carbonate deposits.

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4.3 Article 2

Author’s contribution

Pseudophapydionininae of the Iberian Ranges (Cenomanian, Iberian peninsula)

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PhD candidate contribution: L.C. designed the hypothesis, analyzed samples and thin sections, took iamges of the facies components and faunal content, conducted field trips collecting samples and measuring stratigraphic columns, conducted the architectural analysis proposing differences between the species described, wrote the manuscript and prepared figures.

SPANISH JOURNAL OF PALAEONTOLOGY

Pseudorhapydioninae of the Iberian Ranges (Cenomanian, Iberian Peninsula)

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ABSTRACT

Pseudorhapydionina laurinensis, *P. dubia*, *P. anglonensis* and *Pseudorhipidionina casertana* (Subfamily Pseudorhapydioninae) from the Iberian Range are re-studied. The age of the deposits containing these species is late Cenomanian. However, a small *Pseudorhapydionina* (named in this work as *P.* aff. *laurinensis*) occurs in the lower Cenomanian deposits suggesting that the origin of the group is in the earliest Cenomanian.

Keywords: Pseudorhapydioninae, porcelaneous foraminifera, Cenomanian, Iberian Ranges, Spain.

RESUMEN

En este trabajo se han restudiado los géneros *Pseudorhapydionina laurinensis*, *P. dubia*, *P. anglonensis* y *Pseudorhipidionina casertana* (Subfamilia Pseudorhapydioninae) de la Cordillera Ibérica. La edad asignada a los depósitos que contienen estos taxones es Cenomaniense superior. No obstante, especímenes de pequeño tamaño, atribuidos en este trabajo a *P.* aff. *laurinensis*, han sido también encontrados en dépositos atribuidos al Cenomaniense inferior, lo que sugiere un origen del grupo en la base del Cenomaniense.

Palabras clave: Pseudorhapydioninae, foraminíferos porcelanáceos, Cenomaniense, Cordillera Ibérica, España.

1. INTRODUCTION

The Iberian Ranges consist of a NW-SE intra-plate fold belt extending about 400 km in length and more than 200 km in width at the east of the Iberian Peninsula, and surrounded by the Ebro, Duero and Madrid basins and the Valencia Trough (Capote *et al.*, 2002). The Iberian Ranges were formed as the result of the Alpine Orogeny, and within them, five structural units are identified: the Demanda-Cameros (NW), Aragonian Branch (central NE), Maestrazgo (SE), Castilian Branch (central SW) and Sierra de Altomira (SW) (Fig. 1a). The Castilian Branch and Maestrazgo units have been the only ones considered in this work. The Catalanids are included in the latter unit.

During Cenomanian times, the area currently occupied by the Iberian Ranges was a SE-NW elongated intra-continental basin (Iberian Basin) developed between the Iberian and Ebro massifs, acting as a seaway between the Tethyan Ocean in the south-east and the Atlantic Ocean towards the north (Caus *et al.*, 2009 and the papers cited therein). In this basin, the development of shallow-water carbonate platforms with a tropical to subtropical climate and an oligotrophic to mesotrophic environmental regime favored the settlement of an abundant fauna of porcelaneous foraminifera with a high to moderate k-strategy, such as the Alveolinoideans and the Soritoideans. The former group was widely studied in the 1930s by Reichel (1936-37), and updated later by Calonge *et al.* (2002) and Vicedo *et al.* (2011), but no new detailed studies have been made after the work of Calonge (1989, 1996) for the Soritaceans.

Thus, the aim of this work is to restudy the representatives of the Pseudorhapydionininae subfamily from the Iberian Ranges (E of Spain) in order to enhance their biostratigraphic and palaeogeographic distribution in this area of the western Tethys, in the context of the Cenomanian Soritoidean revision. The study has been based mainly on four sections from the Serranía de Cuenca (Castilian Branch, Cuenca province), although complementary samples have been also taken in the Maestrazgo (Puerto de Villarroya and Puerto del Remolcador sections, Teruel and Castellon provinces), and from the Catalanids outcrops (Prat de Compte, Llaveria and Tarragona, Tarragona province) (Fig. 1b). Moreover, material collected by Calonge (1989) and deposited in the University of Alcalá de Henares was also re-studied. The new material treated in this work has been deposited at the Department of Geology of the Universitat Autònoma de Barcelona. The figured specimens are deposited in the collection of Palaeontology under the acronym PUAB 82473-82479.

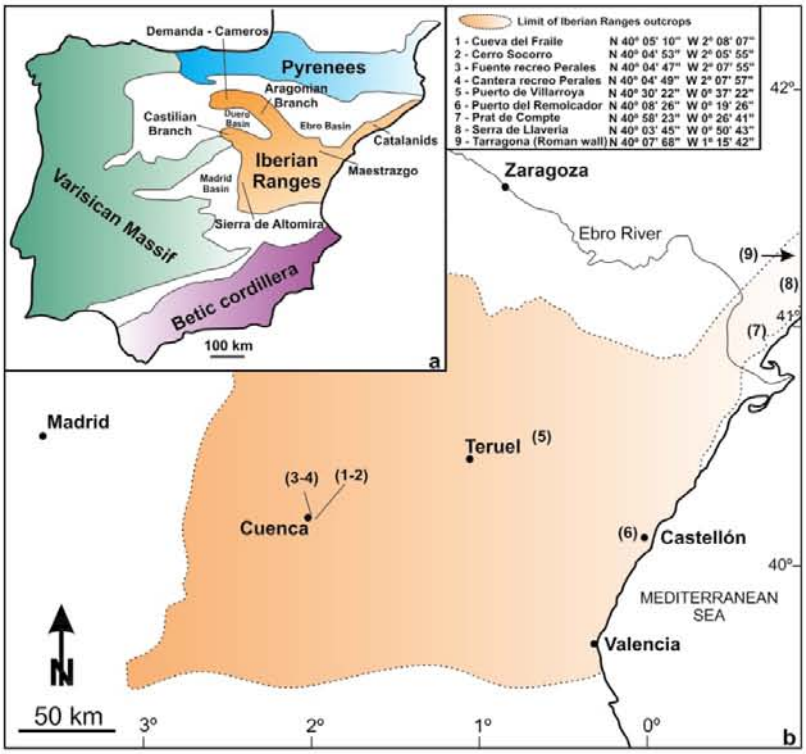

Figure 1. a) Location of the Iberian Ranges in the Iberian Peninsula. **b)** Position of the studied sections and outcrops. 1-4 Castilian Branch (Serranía de Cuenca): 1. Cueva del Fraile; 2. Cerro Socorro; 3. Fuente de Recreo Perales; 4. Cantera de Recreo Perales; 5-6 Maestrazgo: 5. Puerto de Villarroya (A-226 road); 6. Puerto del Remolcador (CV-190 road); 7-9 Catalanids: 7. Prat de Compte; 8. Serra de Llaveria; 9. Tarragona (Roman wall). See Calonge (1989) for further information.

2. CENOMANIAN STRATIGRAPHY

In the Iberian Ranges, the Cenomanian sequence is divided generally into five lithostratigraphic units (Vilas *et al.*, 1982). From bottom to top, they are (Fig. 2):

1. Chera Formation. This basal unit is constituted by green marls interbedded with partially dolomitized grey limestones. The unit contains a rich fauna of oysters and larger foraminifera; among this last group *Cuneolina pavonia* d'Orbigny, *Orbitolina* (*Conicorbitolina*) cf. *cuvillieri* (Moullade), *O.* (*C.*) *corbarica* Schroeder, *Peneroplis parvus* De Castro, *Ovalveolina maccagnoe* De Castro, *Sellialveolina quintanensis* Vicedo, Calonge & Caus (note that this species is generally named *Sellialveolina* gr. *vialli* in previous works), and rare small *Praealveolina iberica* Reichel. The age of this unit is earliest Cenomanian (Caus *et al.*, 2009). The Chera Formation, latest Albian in age (Caus *et al.*, 2009), overlays the Aras de Alpuente Formation.

This unit yields *Pseudorhapydionina* aff. *laurinensis*.

2. Alatoz Formation. This consists of laminated limestone and dolostone, characterized mainly by the occurrence of *Praealveolina iberica* associated to *O.* (*Orbitolina*) *concava* (Lamark), *O.* (*O.*) *duranddelgai* Schroeder and *Charentia cuvillieri* Neumann, among others. The age is early Cenomanian (Caus *et al.*, 2009).

3. Villa de Ves Formation. This unit comprises thin-bedded to massive limestones intercalated with marly limestones passing upwards to dolostone. The larger foraminifera are represented by *Orbitolina (C.) conica* (d'Archiac), *Charentia cuvillieri*, *Praealveolina debilis* Reichel and *Sellialveolina gutzwilleri* Vicedo, Calonge & Caus. In addition, a rich association of nezzazatids (*Nezzazata simplex* Omara, *Merlingina cretacea* Hamaoui & Saint Marc, *Biplanata peneropliformis* Hamaoui & Saint Marc, *Biconcava bentori* Hamaoui & Saint Marc and *Coxites zubairensis* Smout) characterizes this unit. A middle Cenomanian age is given to this unit (Calonge *et al.*, 2002; Caus *et al.*, 2009).

4. Casa Medina Formation. Nodular limestone and dolomites with a rich fauna of porcelaneous foraminifera that include alveolinids (*Praealveolina tenuis* Reichel, *Praealveolina simplex* Reichel, *Ovalveolina ovum* (d´Orbigny) and *O.* cf. *crassa* De Castro) and pseudorhapydionines (*Pseudorhapydionina dubia* De Castro, *P. anglonensis* Cherchi & Schroeder,

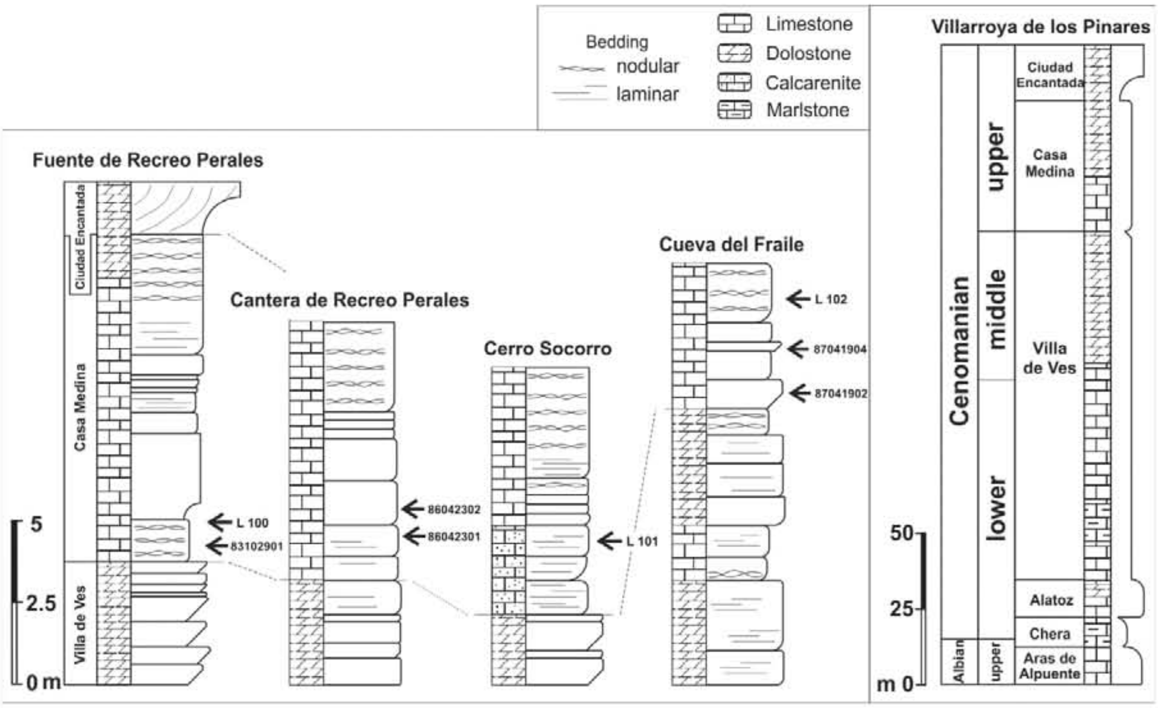

Figure 2. Schematic correlation of the Serranía de Cuenca sections (Castilian Branch) with the stratigraphic position of the samples containing Pseudorhapydionines. Note that the reference section is from Villarroya de los Pinares section (Maestrazgo) (redrawn from Caus *et al.*, 2009). See coordinates in Fig. 1B. Samples repository: L100 = PUAB 82475; L101 = PUAB 82476; L102 = PUAB 82478. Remaining samples have been taken from Calonge (1989).

P. laurinensis De Castro and *Pseudorhipidionina casertana* De Castro). No orbitolinids or rhapydioninids are present in this unit, which is dated as late Cenomanian.

5. Ciudad Encantada Formation. The unit is constituted mainly by dolomites, and the larger foraminifera occur only sporadically when the dolomitization is less intense.

In the Catalanids, the deposits of Cenomanian age are represented only by a few meters of limestone and dolomites attributed to the Serra de Llaveria Formation (Robles, 1982), which are contemporaneous with the Casa Medina and Ciudad Encantada Formations. In this area the Cenomanian deposits lie on the terrigenous Utrillas Formation. The limestones of the Serra de Llaveria Formation contain *Pseudorhapydionina dubia*, *P. anglonensis*, *P. laurinensis* and *Pseudorhipidionina casertana*.

From a depositional point of view, the Cenomanian deposits of the Iberian Basin belong to two consecutive cycles, separated by a major unconformity occurring at the middle Cenomanian. At that time an important sea-level drop caused a regional episode of subaerial exposure across most Iberian shallow marine areas (Giménez, 1987; Martín-Chivelet & Giménez, 1993). The deposits of the lower cycle are represented by Chera, Alatoz, and Villa de Ves, while those of the upper cycle are constituted by the Casa Medina and Ciudad Encantada formations or their contemporaneously equivalent deposits in the Catalanids.

3. SYSTEMATICS

Phylum FORAMINIFERA d'Orbigny, 1826 Pawlowski *et al.*, 2013
Class TUBOTHALAMEA Pawlowski *et al.*, 2013
Order MILIOLIDA (Delage & Hérouard, 1896) Pawlowski *et al.*, 2013

Remarks. In this paper the classification used for high-level categories, such as phylum, class, and order categories, is from Pawlowski *et al.* (2013).

Superfamily Soritoidea Ehrenberg, 1839

Remarks. Following Consorti *et al.* (2016) the Superfamily Soritoidea should be restricted to porcelaneous foraminifera with planispiral early arrangement of the chambers in A and B generations that may later become uncoiled, flabelliform, or annular, in the adult stage.

Family **Praerhapydioninidae** Hamaoui & Fourcade, 1973

Remarks. See Consorti *et al.* (2015, 2016) for discussion about the Praerhapydioninidae family.

Subfamily Pseudorhapydionininae Consorti *et al.*, 2016
Type Genus *Pseudorhapydionina* De Castro, 1972
Genus *Pseudorhapydionina* De Castro, 1972
Type species *Rhapydionina laurinensis* De Castro, 1965

Description. Globular to subcylindrical porcelaneous foraminifer with planispiral-involute chamber arrangement in the early stage of growth, becoming generally uncoiled in the adult stage. The aperture is cribrate. The marginal chamber lumen is partially subdivided by radial septula. For further details see De Castro in Schroeder & Neumann (1985).

Pseudorhapydionina dubia (De Castro, 1965)
(Figs 3a-3g)

Description. Porcelaneous shell with subglobular-to-cylindrical morphology. The chambers in the early stage of growth are arranged in one and a half to two whorls. The specimens of the Iberian Ranges show four chambers in the first whorl and six or seven in the second one. The uncoiled adult stage consists generally of five cylindrical chambers. The globular early stage reaches a maximum diameter of 0.35 mm with an average of 0.29 mm. The seriate adult stage has an average length of 0.6 mm and the height of the chambers is approximately 0.06 mm. The scarce centered sections show a proloculus of about 40 μm in diameter. The apertural face is convex and the aperture cribate. The intercameral foramina are regularly disposed, forming a circular pattern with three concentric stipple rings in the septa. The chamber lumen is partially divided by radial septula, which number approximately 5-6 per quadrant in the seriate adult stage of growth. Septula are short and their thickness is less than 10 μm.

Remarks. The concentric ring pattern of the foramina observed in the *P. dubia* from the Iberian Ranges can be also observed in De Castro (1985; Pl. 41, Figs 2-6). The circular outline of foraminal disposition is referred always to the seriate chambers. Their presence in the spirally arranged chambers has not been observed.

Stratigraphical and geographical distribution. *Pseudorhapydionina dubia* is a common species in the late Cenomanian of the Iberian Ranges. It frequently occurs in the Serranía de Cuenca (Casa Medina Formation) and in Prat de Compte (Serra de Llaveria Formation).

Pseudorhapydionina anglonensis Cherchi & Schroeder, 1985
(Fig. 3h)

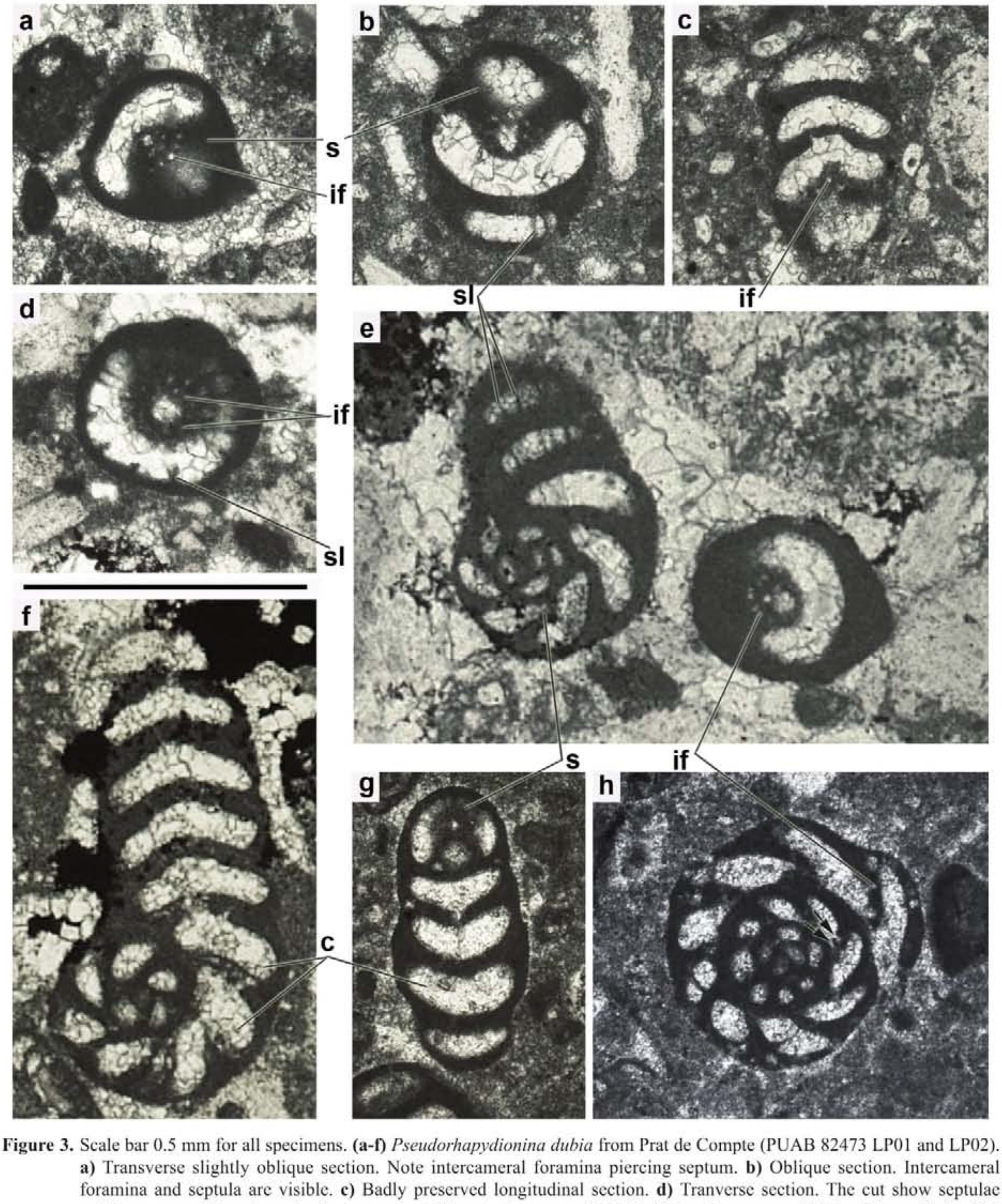

Figure 3. Scale bar 0.5 mm for all specimens. **(a-f)** *Pseudorhapydionina dubia* from Prat de Compte (PUAB 82473 LP01 and LP02). **a)** Transverse slightly oblique section. Note intercameral foramina piercing septum. **b)** Oblique section. Intercameral foramina and septula are visible. **c)** Badly preserved longitudinal section. **d)** Tranverse section. The cut show septulae and intercameral foramina piercing septum. **e)** Close to the equatorial (left side) and tranverse slightly oblique (right side) sections. **f)** Close to the equatorial section. Four seriate chambers are visible. **(g)** *P. dubia* from Serra de Llaveria (sample 80092401 of Calonge, 1989). Longitudinal section. In the upper part, the convexity of the septum simulates the presence of a simple unique aperture. This also happens in a, b, d. **(h)** Equatorial section of *Pseudorhapydionina anglonensis* from Serra de Llaveria (sample 80092401 of Calonge, 1989). The section shows few septula (lower part) and intercameral foramina in interiomarginal position (lasts chambers). Apertures in interimarginal position are also visible in earlier growth stage (arrows). **c**: chamber; **if**: intercameral foramina; **s**: septum; **sl**: septulum.

Description. Porcelaneous globular shell lacking the seriate stage of growth typical of the other species of the genus *Pseudorhapydionina*. The chambers are arranged in 2.5 planispiral whorls. The first whorl consists of seven chambers, the second of eight, while the last incomplete whorl is composed of five chambers. The shells have an average diameter of 0.48 mm, while their proloculi are around 30 µm. The septa are convex and cribbed by foramina located in the interiomarginal position. *Pseudorhapydionina anglonensis* has few and short radial septula subdividing the chamber lumen.

Remarks. Cherchi & Schroeder (1985) state that cribrate aperture is present just in the last chambers, while a simple aperture is present in the early ontogenetic stage of growth. However, in the Iberian material at our disposition, the cribrate aperture is also observed in the early steps of growth (see the arrows in Fig. 3h).

Stratigraphical and geographical distribution. *Pseudorhapydionina anglonensis* has been only found in the Serra de Llaveria Formation (Catalanids).

Pseudorhapydionina laurinensis (De Castro, 1965)
(Figs 4a-4b)

Description. Porcelaneous, subgloblar-to-cylindrical shell. The subglobular early stage, with a size of about 0.33 mm of diameter, consists of two whorls of planispiral chambers. The first whorl hosts six chambers, while the second one has ten. The diameter of the proloculus is approximately 30 µm. The height of the cylindrical chambers is approximately 0.05 mm. The chamber lumen is partially divided by long radial septula, which number approximately 5-6 per quadrant in the seriate stage of growth. Septula thickness is around 15 µm. For further information see De Castro (1985) and Consorti *et al.* (2016).

Remarks. In the deposits of the Chera Formation (early Cenomanian) of the Puerto del Remolcador section (see Calonge, 1989 for details), some specimens of a small *Pseudorhapydionina* (*P.* aff. *laurinensis* in this work) have been observed (Fig. 4a). These specimens differ from *P. laurinensis* type by the smaller size of their adult shells and proloculi. However, the material at our disposal is not enough to prove if it is a new species characterizing the older deposits than those containing *P. laurinensis*. It is worth noting that De Castro (1985) also mentioned "*P. laurinensis*" in association with *S. vialli* in the deposits of early Cenomanian of southern Italy, although the author does not figure it.

Stratigraphical and geographical distribution. *Pseudorhapydionina laurinensis* is rare in the studied samples. It has only been found in the deposits of the Serra de Llaveria Formation, although Calonge (1996) mentioned this species in the deposits of the Castilian branch (Puerto de Villarroya and Morrón de Pinarueco sections). The late Cenomanian age of the specimens of the Iberian Ranges coincides with the age of the *P. laurinensis* type (De Castro, 1985).

Genus *Pseudorhipidionina* De Castro, 1972
Type species *Rhipidionina casertana* De Castro, 1965

Description. Flat, porcelaneous foraminifer with planispiral-involute chamber arrangement in the early stage of growth, becoming uncoiled and flabelliform in the adult stage. The elongate apertural face is pierced by multiple non-aligned openings (cribrate aperture). The marginal chamber lumen is partially subdivided by radial septula. See De Castro in Schroeder and Neumann (1985) for further details.

Pseudorhipidionina casertana De Castro, 1972
(Figs 4d-4e, 4h, 5a-5j)

Description. Porcelaneous flabelliform shell with an acute periphery. The early planispiral-involute stage of growth consists of elongated chambers arranged in one and a half to two whorls, reaching a diameter of 0.55 mm, approximately. The seriate stage is composed, at least, of 10 wide and short chambers averaging 0.04 mm in height. The septa are markedly convex and cribbed by numerous intercameral foramina. The external part of the chamber lumen is partially divided by radial septula. The septula, which has a thickness of around 15-18 µm, may bifurcate at their inner end. They occupy one-third of the chamber lumen.

Remarks. The presence of bifurcate septula has never been highlighted in this taxon, although the character seems to be present with high frequency, especially in the seriate stage of growth. Bifurcate septula are visible in our material and in the specimens figured by De Castro (1985; Pl. 45, Fig. 6).

De Castro (2006) transferred a foraminifer to the genus *Pseudorhipidionina* that was previously described by Crescenti (1964) as *Praerhapydionina murgiana*. However, the small biometrical differences between *P. murgiana* (Crescenti) and *P. casertana* De Castro (see Table 2 in De Castro, 2006) may suggest they are synonyms, although further studies should be done.

Stratigraphical and geographical distribution. This species is widely distributed in the upper Cenomanian samples of the Casa Medina and Serra de Llaveria Formations. It has also been found in the Cenomanian clasts reworked in the Tertiary foreland conglomerates of the Ebro Basin.

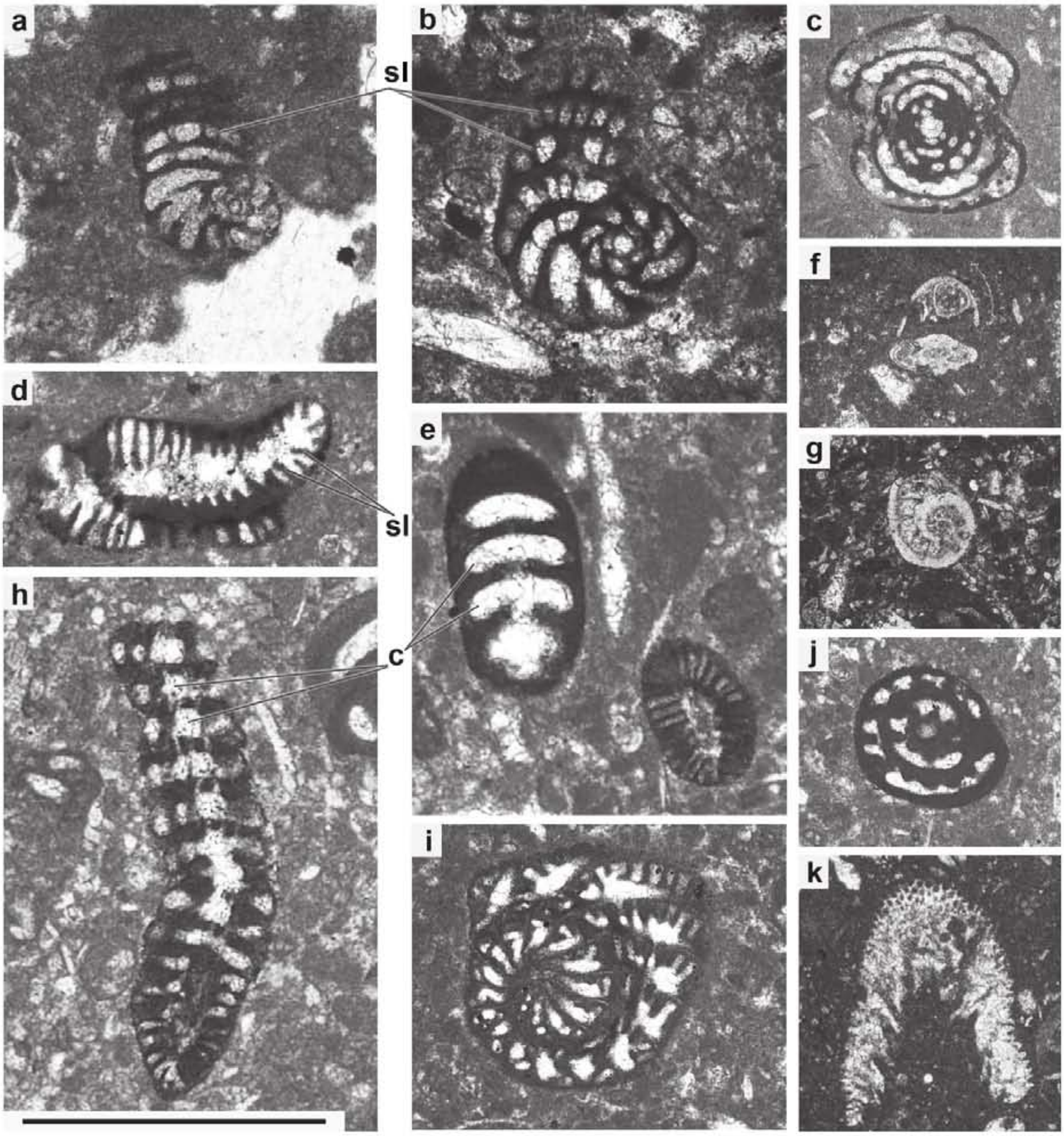

Figure 4. Scale bar 0.5 mm for figures a, b, d, e, h. **a)** Equatorial section of *P.* aff. *laurinensis* from Chera Formation in Puerto del Remolcador (PUAB 82479 LP01). **b)** Equatorial section of *P. laurinensis* from Serra de Llaveria (sample 80092401 of Calonge, 1989). **d)** *Pseudorhipidionina casertana* from Serra de Llaveria (sample 80092401 of Calonge, 1989). Oblique-transverse section of seriate chambers. Note bifurcation at the inner end of a septulum. **e)** Oblique-longitudinal section of a *P. dubia* (left side) and *P. casertana* in transverse section (right side). Specimens from Fuente de Recreo Perale (PUAB 82475 LP02). **h)** *P. casertana* in longitudinal section. Cut also shows the preceding whorl in the spiral stage of growth (lower side of the picture). Specimens from Fuente de Recreo Perale (PUAB 82475 LP02). Scale bar 1 mm for associate fauna in figures c, f, g, i, j, k. **(c, f, i, j, k)** Specimens from Cerro Socorro (PUAB 82476 LP02-03); **(g)** from Fuente de Recreo Perales (PUAB 82475 LP03). **c)** *Cisalveolina* cf. *lehneri*. **f, g)** Axial and equatorial section respectively of *Rotorbinella mesogeensis*. **(i)** *Coxites zubairensis* in transverse section **j)** *Ovalveolina* sp. **k)** Green algae. **c**: chamber; **s**: septum; **sl**: septula.

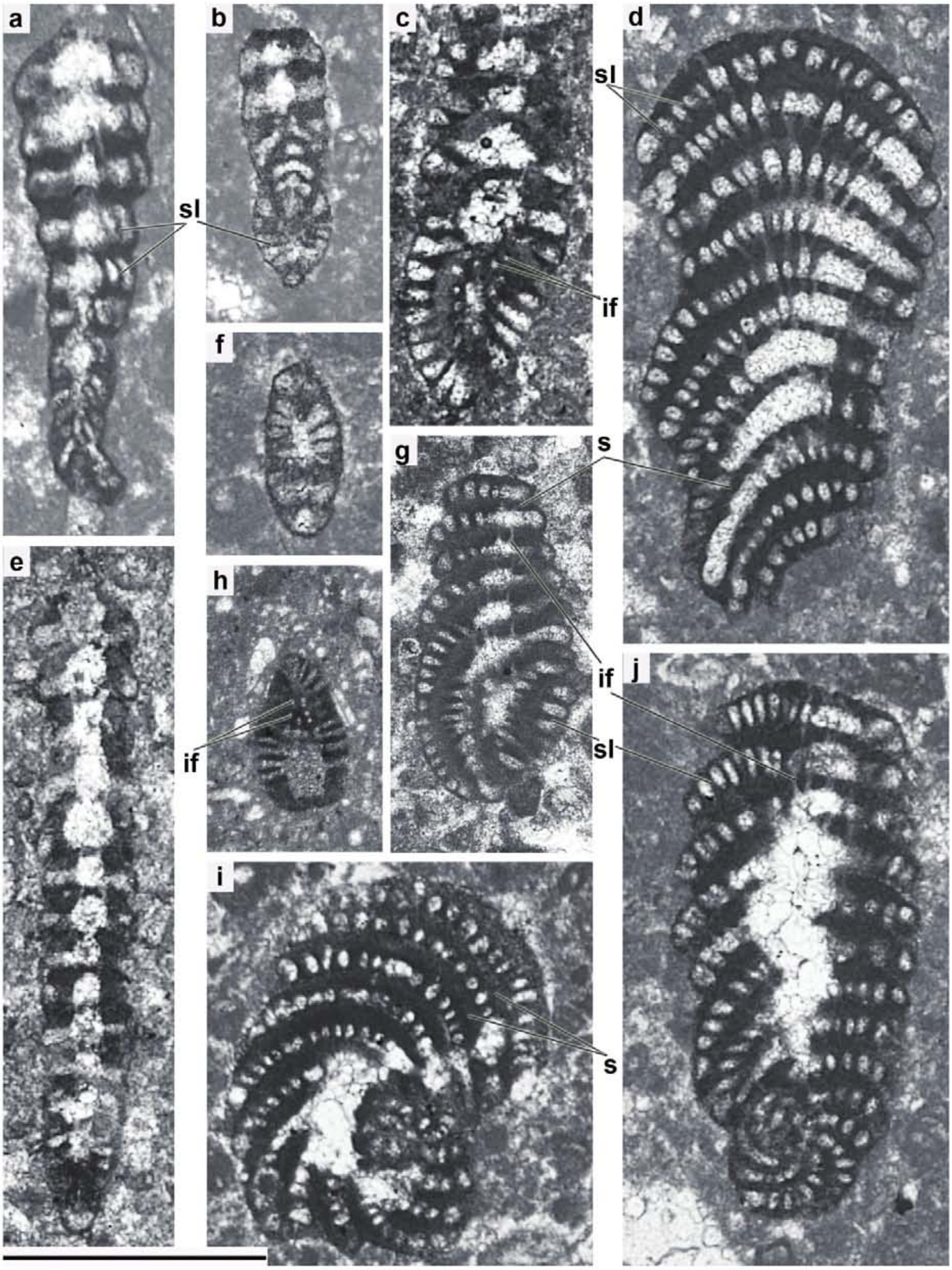
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Figure 5. *Pseudorhipidionina casertana.* Scale bar 0.5. **(a, c, e)** Specimens from Cueva del Fraile section; **(b, f)** from a clast in Tertiary deposits near Prat de Compte; **(d, g, i, j)** from Fuente de Recreo Perales section; **(h)** from Serra de Llaveria section. **a)** Longitudinal section showing septula (PUAB 82473 LP01). **b)** Near to the axial section, septula are shown in the lower part of the specimen (PUAB 82474 LP01). **c)** Longitudinal section, septum cut tangentially shows intercameral foramina (sample 87041904). **d)** Oblique-tangential section of the seriate stage of growth. Septula are absent where cut intercept inner cameral spaces (PUAB 82475 LP01). **e)** Longitudinal section of a badly preserved specimen (sample 87041904). **f)** Transverse slightly oblique section of a small chamber (PUAB 82474 LP01). **g)** Oblique section of several seriate chambers (sample 83102901). **h)** Transverse section showing intercameral foramina (sample 80092401-2 of Calonge, 1989). **i)** Close to the equatorial section of a badly preserved specimen (PUAB 82475 LP02). **j)** Oblique-longitudinal section, seriate chambers are partially dissolved in their central part (PUAB 82475 LP02). **if**: intercameral foramina; **s**: septum; **sl**: septulum.

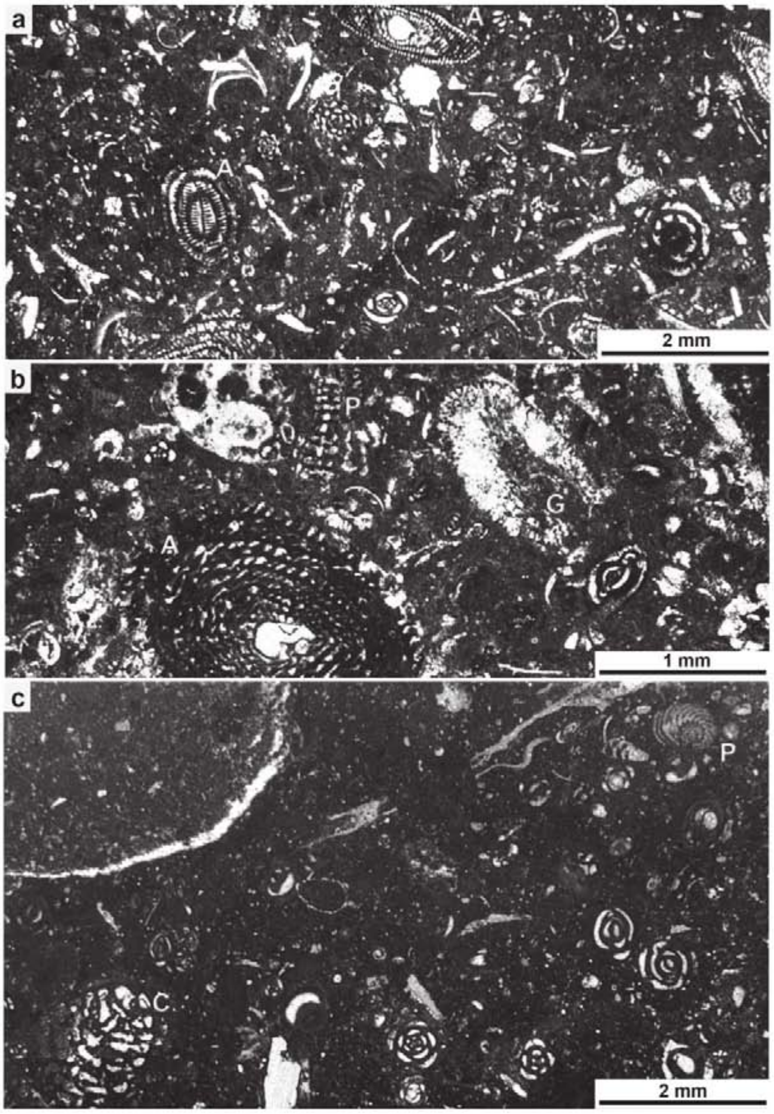

Figure 6. a) Facies from Cerro Socorro section, Serranía de Cuenca (sample L101). Wackestone-packstone with alveolinids (A). The microfacies also contains *Cuneolina* sp., *Pseudorhipidionina casertana*, *Rotorbinella mesogeensis*, *Coxites zubairensis*, nezzazatids, miliolids, green algae and rudist fragments. **b)** Facies from the Cueva del Fraile section, Serranía de Cuenca (sample L102). Wackestone-packestone with *Pseudorhipidionina casertana* (P), green algae (G) and alveolinids (A). The microfacies contains also few miliolids, nezzazatids, green algae and rudist fragments. **c)** Facies from Parco-Peragine (near Bari, SE of Italy), sampled in the same locality of De Castro (2006). Wackestone-packstone with *Psuedorhipidionina 'murgiana'* (P), *Crysalidina gradata* (C), miliolids and echinoderm fragments. In the same sample *Coxites zubairensis*, *Cisalveolina fraasi*, *Pseudolituonella reicheli*, *Dicyclina schlumbergeri*, nezzazzatids and trocholinids are also present.

4. PALAEOENVIRONMENT, AGE AND PALAEOBIOGEOGRAPHY

The facies bearing Pseudorhapydionines from Iberian Ranges are interpreted as shallow-water carbonate platform deposits, ranging from lagoonal to littoral facies. They consist of packstone-wackestones with abundant porcelaneous foraminifera, mainly *Praealveolina,* small rotaliids, some agglutinating forms, green algae, and rudist fragments (Figs 6a-6b). The Iberian facies differ from most of the contemporaneous facies from southern Italy (type localities of *P. dubia*, *P. laurinensis* and *P. casertana*) because the latter contain miliolids and *Cisalveolina* (Fig. 6c).

In the Iberian Ranges, *Pseudorhapydionina laurinensis*, *P. dubia*, *P. anglonensis* and *Pseudorhipidionina casertana* occur only in the deposits of the upper sedimentary cycle (Casa Medina and Serra de Llaveria Formations), attributed to the late Cenomanian (*Praealveolina brevis* and *P. tenuis* biozones, Calonge *et al*., 2002). They are mainly associated with alveolinids (*Praealveolina brevis* and *P. tenuis*) and nezzazatids. *Rotorbinella mesogeensis* is also present. This age is concordant with that attributed to this association in other areas of the Mediterranean Sea and Middle East (De Castro in Schroeder & Neumann, 1985 and the papers cited therein; Whittaker *et al*., 1998; Parente *et al*., 2008; Chiocchini *et al*., 2012; Consorti *et al*., 2015 among others). Outside the Iberian Ranges, the above-mentioned taxa are in the same strata as *Cisalveolina fraasi*, a marker for the late Cenomanian (De Castro, 1983; Frijia *et al*., 2015).

However, the presence of small forms (*P*. aff. *laurinensis* in this paper) associated with *Sellialveolina quintanensis* in the deposits of the Chera Formation suggests that the first representatives of the Pseudorhapydionininae appear in the Iberian Ranges at least at the base of the Cenomanian.

From a palaeogeographical point of view, *Pseudorhapydionina dubia*, *P. laurinensis* and *Pseudorhipidionina casertana* showed a broader distribution along the Cenomanian Tethyan shallow-water deposits, from the eastern shores of the Iberian Peninsula and Sardinia at the northwest to the Zagros Mountains in Iran, and probably Oman at the southeast (Fig. 7). *Pseudorhapydionina anglonensis* has been only mentioned in the Iberian Peninsula (this work), Sardinia (Cherchi & Schroeder, 1985), and central Italy (Chiocchini *et al.*, 2012). However, the lack of references from this species in the Middle East may be due to a mistake in its identification due to the difficulties to distinguish the juvenile tests of *P. anglonesis* and *P. dubia*.

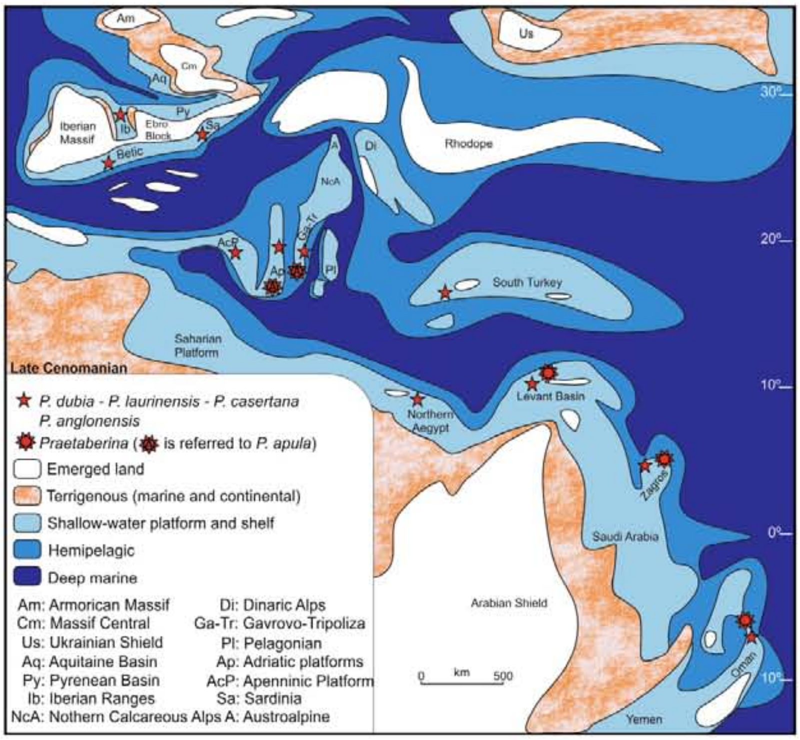

Figure 7. Palaeogeographic reconstruction of central and eastern Tethys during late Cenomanian. Redrawn and simplified after Dercourt *et al.* (2000), Caus *et al.* (2009), and Zarcone *et al.* (2010). References for each locality: Iberian Ranges (Calonge, 1989, 1996 and this work); Greece (Fleury, 1980); Sardinia (Cherchi & Schroeder, 1985); Adriatic platforms (De Castro, 2006; Velić, 2007; Spalluto, 2012); Apenninic Platform (De Castro, 1965; Chiocchini *et al*., 2012); north of Egypt (Bauer *et al*., 2002); south of Turkey (Bignot & Poisson, 1974); Lebanon, Levant Basin (Saint-Marc, 1974); Iran and Oman (Smith *et al*., 1990; Afghah & Fadei, 2014; Consorti *et al*., 2015).

5. CONCLUSIONS

In the Iberian Ranges, the subfamily Pseudorhapydionininae is represented by *Pseudorhapydionina laurinensis*, *P. dubia*, *P. anglonensis* and *Pseudorhipidionina casertana*. These species characterize the shallow-water carbonate deposits of the Cenomanian upper sedimentary cycle (Casa Medina and Ciudad Encantada Formations), late Cenomanian in age. However, in the deposits of the lowermost lower sedimentary cycle (Chera Formation), a small *Pseudorhapydionina,* named here as *P.* aff. *laurinensis,* occurs. Its age is early Cenomanian, which places the origin of the group, at least, in the earliest Cenomanian.

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Chapter 5

ADDING NEW DATA TO THE LATE CRETACEOUS GCMC

5.1 Overview

The Late Cretaceous GCMC (KGCMC) is bracketed between two mass extinction events: the Cenomanian-Turonian boundary (CTB) event and the Cretaceous-Paleogene (K-Pg) boundary event.

Previous knowledge on the morpho-structural characters of LBF tests and on their stratigraphic distribution in the Turonian-Maastrichtian interval suggests that two main phases of the Late Cretaceous GCMC were registered in the studied areas, from early Turonian to early late Campanian, as follows. (1) Early Turonian–early Coniacian interval characterised by post crisis survival assemblages with very low diversity and low abundance, followed by the appearance of new genera, usually monospecific, characterized by small size and poorly developed dimorphism (r-strategists). This phase was recently studied by Arriaga (2016). (2) Late Coniacian–early late Campanian phase with dominance of a few genera, which attain high specific diversity and some of the dominant genera attain a very large size. During this phase the LBF comunities may have evolved separately in each palaeobioprovince: Pyrenean and Tethyan showing strong endemism. However, the details of both palaeobioprovinces are poorly known, particularly for the Tethyan palaeobioprovince.

Previous to this thesis, several papers have been published on the Pyrenean LBF from the Late Cretaceous Global Community Maturation Cycle (including Hottinger, 1966, on rotaloideans and Orbitodes; Hottinger et al., 1989 on the fabularids; Boix, 2009 on rotaloideans; Hottinger and Caus, 2009, on meandropsinids; Caus et al., 2013 on *Broeckina*; Albrich, 2014, 2015 on “primitive” *Orbitoides* and selected agglutinated LBF). In general, it was suggested that large meandropsinids and alveolinids are exclusively from the Pyrenean paleobioprovince, whereas rhapydioninids and porcelaneous generalike *Murgella*, *Keramosphaerina* and *Scandonea* are only from the Tethyan palaeobioprovince (e.g. Fleury and Fourcade, 1985; Caus and Hottinger, 1986; Goldberck and Langer, 2009). The agglutinated *Cuneospirella* is known only from the Tethyan palaeobioprovince. Large miliolids (lacazines) are shared in both palaeobioprovinces but they are representedby different species (Hottinger et al., 1999), and are much more diversified in the Pyrenean palaeobioprovince.

Regarding the rotaloideans, few papers have been published on their presence in the Tethyan area; only the work of Torre (1966) was dedicated to the description of the new taxa: *Rotorbinella scarsellai* and *Stensioeina surrentina* from the vicinity of Sorrento (South-west of Italy), although there were reports of undetermined rotalids in several geologic or palaeontological works (e.g. Lupero Sinni and Reina, 1996; Carannante et al., 1998; Tentor, 2007; Schlüter et al., 2008; Brandano and Loche, 2014).

Thesis paper 3 deals with the description of a new species of *Pseudorhapydionina* in the Santonian of the Pyrenees. Paper 4 is dedicated to the rotaloideans of the Tethyan palaeobioprovince, while paper 5 deals with some previously non-described rotaloideansfrom the Pyrenean palaeobioprovince.

5.2 Article 3

Author's contribution

Pseudorhapydionina bilottei n. sp., anendemic foraminifera from the post Cenomanian/Turonian boundary (Pyrenees, NE Spain)

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PhD candidate contribution: L.C. designed the hypothesis,conducted field trips collecting samples and measuring columns, analyzed samples and thin sections identifying the new taxa, described components of the facies and the faunal content, collected bibliographical information, conducted the architectural analysis proposing differences between the species described and those already published, wrote the manuscript and prepared figures.

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Pseudorhapydionina bilottei sp. nov., an endemic foraminifera from the post-Cenomanian/Turonian boundary (Pyrenees, NE Spain)

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ABSTRACT

A new species of the foraminiferal genus *Pseudorhapydionina* is reported from the Santonian shallow-water carbonate and mixed deposits of La Cova Unit, in the Montsec and Pedraforca thrust sheets (Southern Pyrenees, NE Spain). *Pseudorhapydionina bilottei* sp. nov. differs from the Cenomanian species of the genus in its larger test size and the number of chambers in its early planispiral-involute stage. The discovery of *P. bilottei* sp. nov in the Santonian indicates that the genus *Pseudorhapydionina* escaped extinction during the Cenomanian-Turonian boundary (CTB) event in the Pyrenean bioprovince. A new subfamily Pseudorhapydionininae is described.

1. Introduction

The genus *Pseudorhapydionina* De Castro, 1972, and its allies *Edomia* Henson, 1948, *Cycledomia* Hamaoui, 1964, *Pseudorhipidionina* De Castro, 1972, and *Praetaberina* Consorti et al., 2015, comprise larger benthic foraminifera (LBF) with porcelaneous tests, cylindrical, fan-shaped to discoidal, with an early planispiral-involute chamber arrangement that may become uncoiled or flabelliform-to-cyclical in adult stages. The apertural face is pierced by multiple cribrate openings. The marginal chamber lumen is partially divided by radial septula (subepidermal partitions in Henson, 1948; beams in De Castro, 1985; "subepidermal lâmes" in Fleury, 1996), whereas in the central area pillars crossing the chamber lumen from bottom to top may be present.

Pseudorhapydionina and its allies, included in the superfamily Soritoidea Ehrenberg, 1839, are traditionally considered as characterizing the shallow-water carbonate deposits of the latest Albian?-Cenomanian (Schroeder and Neumann, 1985). This interval corresponds to the mid-Cretaceous Global Community Maturation Cycle (GCMC) of Hottinger (1998, 2001). However, the current literature suggests a non-uniform generic and/or specific geographic distribution. In the "Mediterranean" Tethys (Tethyan LBF palaeobioprovince in Caus et al., 2007) the genera *Pseudorhapydionina* and *Pseudorhipidionina* were reported from the Iberian Peninsula (Calonge, 1989; Calonge, 1996; Caus et al., 2009), Italy (De Castro, 1972, 2006; Chiocchini and Mancinelli, 1977; Mancinelli and Chiocchini, 2006; Chiocchini et al., 2012; Spalluto, 2012), Croatia (Gušić and Jelaska, 1990; Velić and Vlahović, 1994), Greece (Fleury, 1980), the Middle East (Hamaoui, 1966; Saint-Marc, 1975; Afghah and Fadei, 2014), and North Africa (Kuss and Malchus, 1987; Bauer et al., 2002). *Edomia* and *Cycledomia* seem to be restricted to the Eastern Tethys (Whittaker et al., 1998), and *Praetaberina* has been recently mentioned in the Eastern and Central Tethys (Consorti et al., 2015). In these areas, the mid-Cretaceous GCMC Soritoideans are associated to rhapydioninids and/or alveolinids. In the Caribbean LBF palaeobioprovince, only the genus *Pseudorhapydionina* has been reported from México (Michaud et al., 1984; Rosales-Domínguez et al., 1997; Aguilera-Franco, 2003) and Cuba (Díaz-Otero and Furrazola-Bermúdez, 1988). Cenomanian Alveolinoideans do not occur in the Cenomanian of the Caribbean palaeobioprovince, although *Sellialveolina drorimensis* (Reiss, Hamaoui and Ecker, 1964) has been recorded in the Peruvian platform associated with the unclear "meandropsinid" larger porcelaneous foraminifer *Perouvianella peruviana* (Steinmann, 1929) (Jaillard and Arnaud-Vanneau, 1993).

Nevertheless, neither *Pseudorhapydionina* and nor its allies have been recorded from the mid-Cretaceous GCMC deposits of the

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Pyrenees, although they are very abundant in the nearby age-equivalent deposits of the Iberian Range (Calonge, 1989; Calonge, 1996; Caus et al., 2009).

In recent papers (Calonge et al., 2002; Hart et al., 2005; Parente et al., 2008; Caus et al., 2009; Consorti et al., 2015; Frijia et al., 2015 among others) it is widely accepted that the genus *Pseudorhapydionina* and its allies disappear near the Cenomanian-Turonian boundary (CTB) together with other groups of LBF with an extreme or moderate K-strategy of life (e. g., the Alveolinoideans), when a major extinction took place in the marine realm (Sepkoski, 1996) probably associated with the Oceanic Anoxic Event (OAE2 or Bonarelli Event, Schlanger et al., 1987).

New mapping and detailed stratigraphical studies on the Upper Cretaceous carbonate deposits of the South-central Pyrenees (NE Spain) show the occurrence of *Pseudorhapydionina* in the shallow-water deposits of the upper part of the La Cova Unit, which age, constrained by strontium isotope stratigraphy (SIS), is early Santonian (Boix et al., 2011). The presence of *Pseudorhapydionina* in the upper Cretaceous deposits of Southern Pyrenees was previously recorded by Bilotte (1984, pl.12, fig.7-9) in Sant Salvador de la Vedella (Llobregat valley, Pedraforca thrust sheet) under the specific name of *P. laurinensis* De Castro (the type-species of the genus *Pseudorhapydionina*), and Boix (2004, pl.21, figs 7-9 and 13-16) in the Montsec Mountains (Montsec thrust sheet) as *Pseudorhapydionina* sp. Deloffre and Hamaoui (1969) also figured a possible *Pseudorhapydionina* section (*Rhapydionina* sp. in their work, pl. 3 fig. 4) from the "Soumoulou Breccia" (near Pau, SW France); however, the section shown in this latter work does not display diagnostic characters permitting its identification at generic level.

In the Late Cretaceous GCMC *Pseudorhapydionina* is associated with *Martiguesia cyclamminiformis* Maync, 1959, *Ramirezella montsechiensis* (Caus and Cornella, 1981), *Lacazina pyrenaica* Hottinger, Drobne and Caus, 1989, *Palandroxina taxyae* Fleury and Tronchetti, 1994, *Helenalveolina tappanae* Hottinger, Drobne and Caus, 1989, *Iberorotalia reicheli* (Hottinger, 1966), *Calcarinella schaubi* (Hottinger, 1966), and *Orbitokathina vonderschmitti* Hottinger, 1966, which at present are endemic of the Pyrenean palaeobioprovince (Caus et al., 2007).

Thus, the aim of this paper is to re-examine the architecture of the post-CTB *Pseudorhapydionina* specimens from samples of the same localities that have been previously studied by Bilotte (1984) and Boix (2004), in order to clarify whether the Pyrenean Late Cretaceous GCMC taxon is a CTB survivor or a newcomer characterized by convergent features. In addition, the new subfamily Pseudorhapydionininae is described.

2. Geological setting

The studied samples were collected from the Montsec and Pedraforca thrust sheets, two Southern Pyrenean tectonic units displaced south during the Pyrenean (Alpine) rogeny (Muñoz, 1985) (Fig. 1). They belong to the La Cova Unit, a well-known stratigraphic unit informally defined in the Montsec Mountains by Pons (1977); deposits with the same lithology and stratigraphic position crop out also in the Pedraforca thrust sheet (Figs. 2, 3).

In the Montsec Mountains the La Cova Unit (Coniacian-Santonian) discordantly overlies the micritic limestones of the Pardina Formation (Turonian, *H. helvetica* and *M. schneegansi* zones, Caus et al., 1993) and is overlain through an erosive contact by the Font de les Bagasses Unit (lower Campanian, Albrich et al., 2014). The deposits of La Cova Unit, with a thickness of 120 m in the Pla d'Escumó section (Fig. 2A), comprise a complete cycle of sedimentation that is composed of two successive sedimentary sub-cycles. Each sub-cycle is characterized by a distinctive assemblage of larger foraminifera dated as Coniacian and Santonian, respectively (Boix et al., 2011), and constituted by a bar-lagoon complex system that includes tidal delta and washover deposits (Caus et al., 1999). *Pseudorhapydionina* occur only in the upper sub-cycle, characterized by bedded packstone-grainstone alternating with marly limestone and nodular marls hosting rudists, corals, gastropods, and benthic foraminifera (Fig. 3A).

In the Pedraforca thrust sheet, the La Cova Unit unconformably overlies Triassic deposits (Bilotte, 1984). In the section measured in Sant Salvador de la Vedella, La Nou de Bergadà (Figs. 1 and 2B), the La Cova Units were represented by 20 m of grey nodular limestone containing a foraminifera and rudist-rich assemblage (see Bilotte, 1984 and Vicens, 1992 for rudist references). *Pseudorhapydionina* occurs in strata at the base of the succession, with an overall texture of skeletal-rich wacke-packstone to packstone, with abundant micritic matrix, peloids and a skeletal assemblage comprising bivalve and green algae fragments, and common large benthic foraminifera (Fig. 3 B-D). The succession ends with sandstones and microconglomerates locally interbedded by oyster-rich marl and marly limestone (Bilotte, 1984).

3. Material and methods

The study is based on 45 thin-sections from 10 samples of cemented carbonate rocks. Samples labeled NouC1 and NouC2 were taken near the cemetery of La Nou del Bergadà village (coordinates: N 42°10′05″ – E 1°′43″). Samples labeled MB-16, MFF-

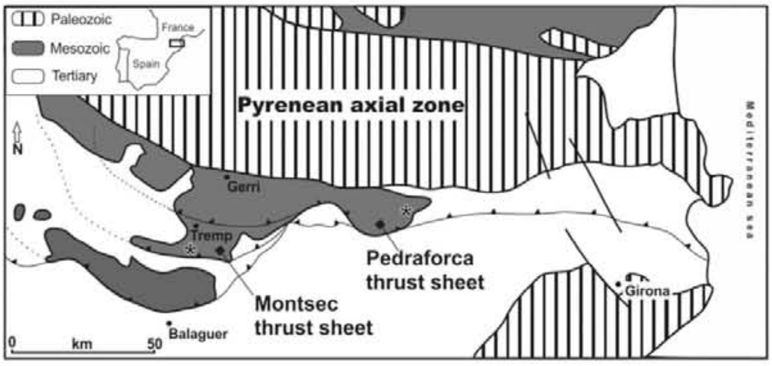


Fig.1. Montsec and Pedraforca thrust sheets with the localization of the study areas (asterisks).

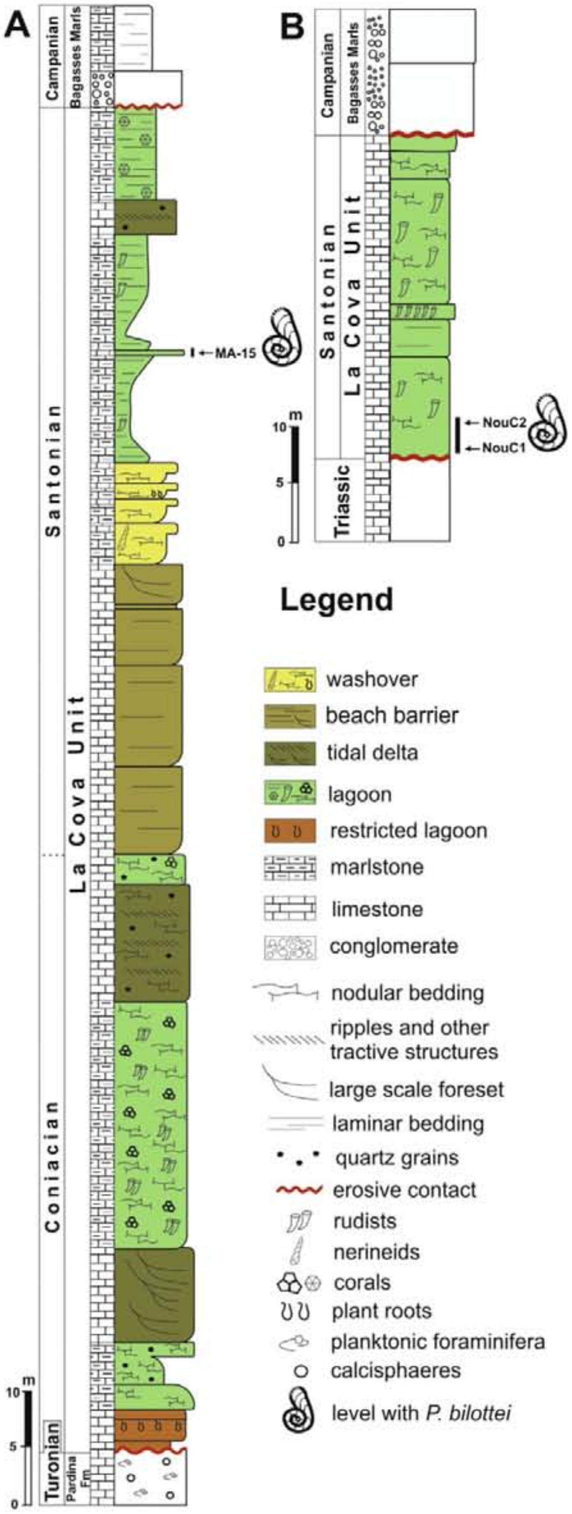


Fig. 2. La Cova limestone succession in the Montsec A and Pedraforca B thrust sheets. Note the complete sedimentary succession in the Montsec thrust sheet and its reduction in the Pedraforca thrust sheet due to tectonics, and the relative position of *Pseudorhapydionina* level in both stratigraphic sections.

14, MFF-15, MA-15, MFB-3 and MFP-8 are from an equivalent stratigraphic level in the Els Barranquils, Les Fonts Fredes, Pla d'Escumó, Terradets, and Font de la Plata sections in the Montsec Mountains (see their geographic position in Boix, 2004).

As a whole, more than 50 random sections have been used to study and describe the new taxon. The figured and supplementary material has been deposited in the collection of Micropaleontology of the Universitat Autònoma de Barcelona (Spain) under the PUAB numbers 82453 – 82457.

4. Systematics

Phylum Foraminifera d'Orbigny, 1826 Pawlowski et al., 2013

Class Tubothalamea Pawlowski, Tiszka, Holzmann, 2013

Order Miliolida (Delage and Hérouard, 1896) Pawlowski et al., 2013

Remarks. In this paper the classification used for high level categories, such as phylum, class and order categories is from Pawlowski et al. (2013).

Superfamily Soritoidea Ehrenberg, 1839

Remarks. Here we suggest restricting the superfamily Soritoidea to porcelaneous foraminifera with planispiral early arrangement of the chambers in A and B generations that may later become uniserial, flabelliform, or annular, with a probable origin from small Early Cretaceous "peneroplid" forms. Therefore, the Late Cretaceous Meandropsinidae Henson, 1948, (as redefined by Hottinger and Caus, 2009) included by some authors in the Soritoidea (e. g., Haynes, 1981; Loeblich and Tappan, 1987; Boudagher-Fadel, 2008), and with an "ophtalmidiid" origin should be removed from the Soritoidea and transferred to Ophtalmidioidea *sensu* Haynes (1981). However, some genera included by these authors in the Meandropsinidae (e.g., *Broeckina* Munier-Chalmas, 1882, see Cherchi and Schroeder, 1975; Caus et al., 2013 for architectural details), lack the diaphanous umbo defining the family Meandropsinidae, and should therefore remain in the Soritoidea. Further studies are needed to assess the relationship between the Mesozoic Soritoideans and those morphologically similar occurring in the Cenozoic and/or recent, before drawing conclusions about this superfamily.

Family Praerhapydioninidae Hamaoui and Fourcade, 1973

Remarks. In spite of the problems in the description of the subfamily Praerhapydionininae (see Fleury, 1997; Consorti et al., 2015 for comments), in this paper it is preferred to rank up the subfamily to family. The family Praerhapydioninidae includes all the Soritoideans with planispiral-involute chamber arrangement in the early stage of growth that may become uncoiled or flabelliform-to-cyclical in the adult stage, independently of the shape, number and position of the apertures. The existence of radial septula dividing incompletely the chamber lumen is considered as a characteristic of lower systematic rank than the intercameral foramina disposition in the classification of foraminifera (Hottinger, 1978).

Pseudorhapydionininae new subfamily
(Type genus: *Pseudorhapydionina* De Castro, 1972)

Diagnosis. Porcelaneous shells with planispiral-involute chamber arrangement in the early stage of growth that may become

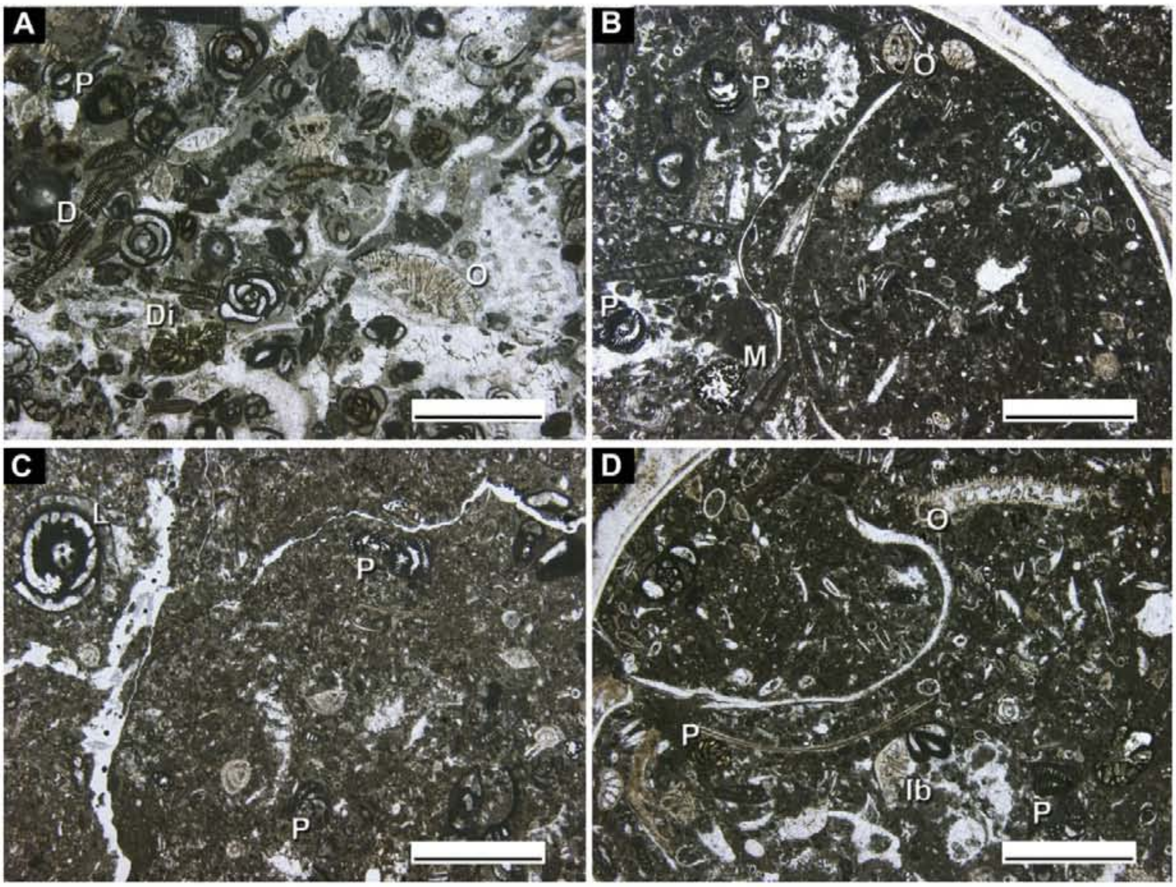


Fig. 3. Microphotographs of representative microfacies. A. Foraminiferal-rich packstone with abundant larger benthic foraminifera, comprising simple and complex miliolids, discoidal agglutinated foraminifera and rotaliids. Note the intense dissolution/replacement of micritic matrix by fine to medium-crystalline calcite cement. B, D. Skeletal-rich packstone with common micritic matrix and peloids. The sample comprises a diverse skeletal allochem assemblage with bivalve and green algae fragments (the latter as occluded molds), large benthic foraminifera (complex miliolids, textulariids and rotaliids). C. Wacke-packstone with common micritic matrix and peloids. The skeletal assemblage is characterized by large benthic foraminifera (complex miliolids and rotaliids) and scattered bivalve and green algae fragments. Rare presence of large vugs resulted from micritic matrix dissolution, now occluded by calcite cements. A. Sample MA-15 (Pla d'Escumó section, Montsec thrust sheet, PUAB 82455) B–D. Sample NouC2 (La Nou, Pedraforca thrust sheet, PUAB 82453). Scale bar 2 mm. Abbreviations: P: *Pseudorhapydionina bilottei* sp. nov; Di: *Dictyopsella kiliani* Munier-Chalmas 1889; D: *Dicyclina schlumbergeri* Munier-Chalmas 1887; O: *Orbitokhatina vondersmitti* Hottinger, 1966; Ib: *Iberorotalia reicheli* (Hottinger, 1966); M: *Martiguesia cyclamminiformis* Maync, 1959; L: *Lacazina pyrenaica* Hottinger, Drobne and Caus, 1989.

uncoiled or fan shaped-to-cyclical in the adult stage. The apertural face is pierced by cribrate openings. The marginal chamber lumen is partially subdivided by radial septula and the central area could have pillars.

Remarks. In the current state of knowledge, this subfamily includes the Cretaceous genera *Cycledomia* Hamaoui, 1964, *Edomia* Henson, 1948, *Pseudorhapydionina* De Castro, 1972, *Pseudorhipidionina* De Castro, 1972 and *Praetaberina* Consorti et al., 2015. The subfamily Praerhapydionininae should be restricted to the genera with a single aperture. However, further studies are needed to determine the relationship between the Cretaceous genera included in Pseudorhapydionininae and those morphologically similar occurring in the Palaeogene.

Genus *Pseudorhapydionina* De Castro, 1972
(Type species: *Rhapydionina laurinensis* De Castro, 1965)

Description. Porcelaneous foraminifer with planispiral-involute chamber arrangement in the early stage of growth, which may become uncoiled in the adult stage with circular outline. The aperture is cribrate. The marginal chamber lumen is partially subdivided by radial septula. For more information see De Castro in Schroeder and Neumann (1985).

Pseudorhapydionina bilottei sp. nov.
(Figs. 4, 5)

1984 *Pseudorhapydionina laurinensis* (De Castro) – Bilotte: pl. 12, figs. 7-9.
2004 *Pseudorhapydionina* sp. – Boix: pl. 21, figs 14-16.

Holotype. Specimen illustrated in Fig. 4I (PUAB 82453 LP05.01).
Holotype measurements. Diameter of the planispiral stage: 1.25 mm; chambers in the first whorl: 7; chambers in the second whorl: 13; proloculus diameter: 88 μm; flexostyle: 35 μm.

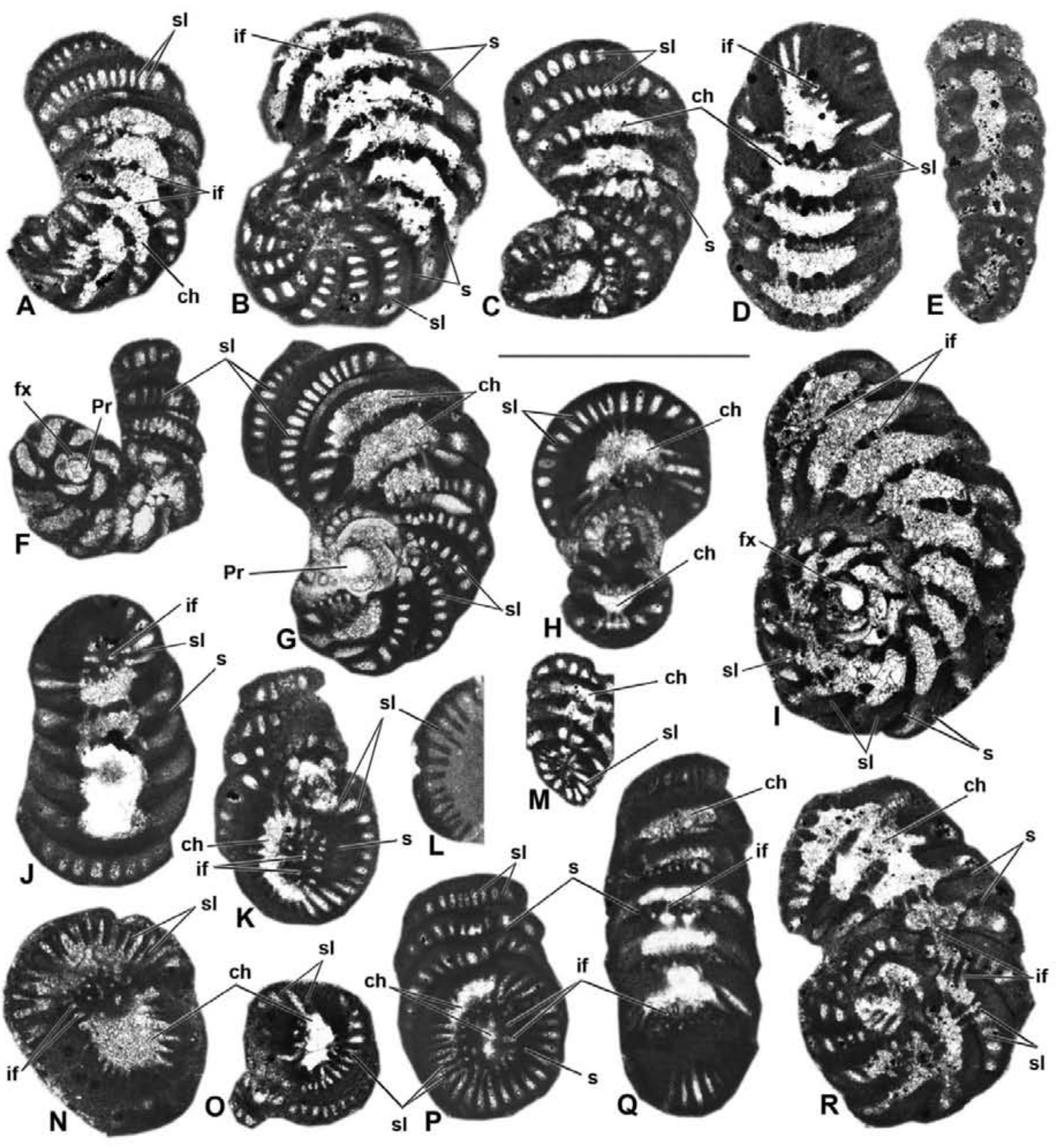


Fig. 4. *Pseudorhapydionina bilottei* sp. nov. A. Oblique nearly subaxial section showing septula, septum with intercameral foramina and empty chamber lumina in the central part of the shell (PUAB 82453 LP07.01). B. Subequatorial section (PUAB 82453 LP01.02). C. Oblique subequatorial section similar to A showing the planispiral growth stage (PUAB 82453 LP08.01). D. Longitudinal section of the uncoiled portion showing the five last chambers, the septa pierced by intercameral foramina and the empty central part of the chambers (PUAB 82453 LP05.02). E. Longitudinal section of a badly preserved specimen (PUAB 82454 LP01.01). F. Equatorial section slightly oblique of an altered specimen showing the spherical proloculus followed by the flexostyle (PUAB 82457 LP01.01). The seriate chambers are tangentially cut showing radial septula. G. Almost centered equatorial section (PUAB 82453 LP10.01). H. Subaxial section showing two spiral whorls with marginal radial septula and the empty central part of chambers (PUAB 82453 LP03.01). I. Holotype. Almost centered equatorial section of a coiled specimen showing a complete set of structural features (PUAB 82453 LP05.01). J. Longitudinal section; note intercameral foramina piercing the septum (PUAB 82453 LP10.02). K. Transverse slightly oblique section cutting from right to left the external wall with the marginal radial septula, the septum pierced by the intercameral foramina, the empty chamber and marginal radial septula in the opposite side (PUAB 82453 LP09.01). L. Transverse section of a half matrix filled chamber showing the septula; note the section is not cutting the cribrate apertures (PUAB 84256 LP01.01). M. Longitudinal section of a small specimen (PUAB 82453 LP04.01). N, O. Transverse slightly oblique sections showing two successive chambers; note in N the septa pierced by intercameral foramina (N: PUAB 82455 LP01.01, O: PUAB 82453 LP01.01). P. Transverse, slightly oblique section showing the septum cut tangentially (PUAB 82453 LP02.01). Q. Longitudinal section (PUAB 82453 LP09.02). R. Subequatorial section (PUAB 82453 LP06.01). Scale bar 1 mm for all the figured specimens. ch: chamber lumen, sl: septulum, s: septum, Pr: proloculus, fx: flexostyle.

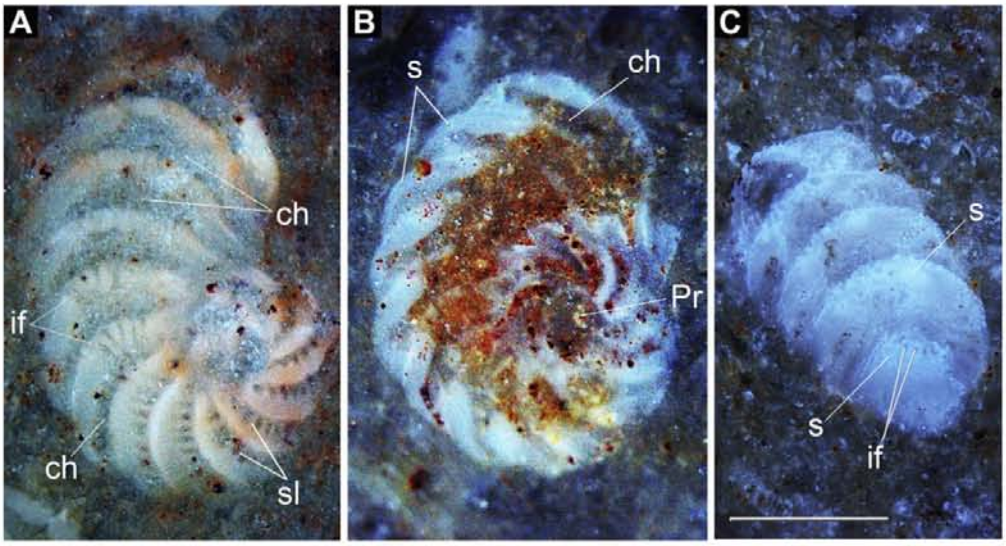


Fig. 5. *Pseudorhapydionina bilottei* sp. nov. from polished slab of the sample NouC2 (PUAB 82453). A. The section shows the spiral chambers with septula and empty seriate chambers, foramina are longitudinally cut in the last part of the coiled stage. B. The coiled stage of growth is here completely represented by two whorls, note septum with relevant convexity in the last chamber. C. Septum convexity is evidenced by less transparency of the shell, foramina occur only the central part of the septum. Scale bar 0.5 mm for all figured specimens.

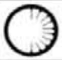
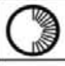
Pseudorhapydionina					
species	*laurinensis*	*dubia*	*anglonensis*	*chiapanensis*	*bilottei*
reference	De Castro, 1965	De Castro, 1965	Cherchi & Schroeder, 1985	Michaud et al., 1984	this work
diameter of the planispiral stage	0.29 mm - 0.33 mm	0.25 mm - 0.42 mm	0.35 mm - 0.4 mm	0.33 mm - 0.4 mm	1.00 mm - 1.3 mm
chambers in the 1st whorl	5	3 - 4	4 - 5	5	6 - 7
chambers in the 2nd whorl	6 - 7	4 - 7	6 - 7	7 - 8	12 - 13
chambers in the seriate stage of growth	7 - 9	3 - 7	not present	4 - 9	4 - 5
width/height (ratio) of the seriate chambers	5 - 6.6	2.6 - 3.5	not present	3.8 - 5	4.4 - 5
type of septula	 thin and long rarely bifurcate	 thin and short, thickened at the base	 thin and medium, thickened at the base	 thick and medium, thickened at the base,rarely bifurcate	 thick and long
septula per quadrant (seriate stage)	6 - 7 in a diameter of 0.4 mm	7 - 9 in a diameter of 0.4 mm	not present	5 in a diameter of 0.4 mm	8 - 9 in a diameter of 0.4 mm

Fig. 6. Similarities and differences of some biometrical parameters in the species currently referred to *Pseudorhapydionina*.

Derivatio nominis. In homage to the French geologist Michel Bilotte who first recorded the genus *Pseudorhapydionina* in the post-CTB deposits.

Diagnosis. Porcelaneous, subglobular-to-cylindrical shell with cribrate apertural face. The spherical megalosphere, with a diameter of about 80–90 μm, is followed by a short flexostyle. The early growth stage consists of two whorls of planispiral-involute chambers; the first whorl consists of 6–7 chambers, the second of 12–13. This early growth stage can reach a maximum diameter of 1.3 mm and is followed by an adult uncoiled stage reaching a length of 0.6–0.8 mm, and formed by about 5 chambers. The height of the successive chambers in the seriate stage is almost constant, measuring approximately 0.15 mm. The lumen of the chambers is partially divided by radial septula, the number of which per quadrant is about 8–9 in a diameter of 0.4 mm, but supplementary septula can be added during ontogeny. They occupy 1/3 of the chamber lumen and their thickness in the seriate chambers is approximately 20 μm.

Similarities and differences. The differences between *P. bilottei* sp. nov. and other species referred to the genus are summarized in Fig. 6. The maximum diameter of the early planispiral stage and the number of chambers per whorl in Cenomanian species are sensibly reduced compared to *P. bilottei*. *Pseudorhapydionina dubia* (De Castro, 1965) differs from *P. bilottei* sp. nov. in the very short radial septula of the former species. The radial septula of *P. laurinensis* (De Castro, 1965) are longer but thinner than in *P. bilottei*; moreover, the width/height ratio of the seriate chambers is higher in *P. laurinensis* than in *P. bilottei*. *Pseudorhapydionina anglonensis* Cherchi and Schroeder, 1985, differs from the other species of *Pseudorhapydionina* in lacking a seriate stage of growth. In contrast, the American *P. chapanensis* Michaud et al., 1984, has a more developed seriate stage than *P. bilottei* (eight chambers in *P. chiapanensis* and five in *P. bilottei*); moreover, in *P. chiapanensis* the radial septula may bifurcate.

Locality and type level. La Nou de Bergadà (200 m from the BV4022 road, near the cemetery of the village, sample NouC2, NE of Spain). Coordinates: N 42°10′05″ – E 1°51′43″. Uppermost part of the La Cova Unit.

Age. Santonian.

Geographic distribution. At present is only known from the Pyrenees.

5. Discussion

The genera of larger foraminifera from Mesozoic to Recent times have been defined by qualitative structural characters of the shell architecture, while the species are defined by quantitative differences in shell proportion, shape and size (Hottinger, 1978; Caus, 1981). Therefore, in agreement with these assumptions, the Pyrenean Late Cretaceous GCMC morphotypes must be ascribed to the genus *Pseudorhapydionina*, but they belong to a separate species (*P. bilottei* sp. nov.) because of their different qualitative characters.

The description of the new taxon suggests that the "Cenomanian" genus *Pseudorhapydionina* probably escaped extinction during the CTB-oceanic event together with *Cuneolina* d'Orbigny, *Pseudonummoloculina* Calvez, and *Rotorbinella* Bandy, supposedly r-strategists adapting to life in meso- or eu-trophic environments (Caus et al., 2010). However, it is interesting to note that the post-CTB *Pseudorhapydionina* has never been found out of the Pyrenean realm, instead the genus was widespread in the Tethyan realm, and it is also present in the Caribbean during the Cenomanian.

The *Pseudorhapydionina*, with *P. bilottei* sp. nov, in the Santonian of the Pyrenean realm, coincides with the recovery of the shallow-water environment after the eutrophication event and the drowning of the Cenomanian carbonate platforms (Simo, 1986; Caus et al., 1993). During the Coniacian-Santonian, an "explosive" development of Late Cretaceous newcomers with a relevant number of endemic taxa (for instance: meandropsinids, lacazinids, large rotaliids and several complex agglutinated foraminifera; see Hottinger et al., 1989; Hottinger and Caus, 2009; Boix et al., 2009, 2011, respectively, for details) took place. The Pyrenees represent a hotspot for larger foraminiferal diversity (Caus and Hottinger, 1986; Goldbeck and Langer, 2009; Caus et al., 2013).

The presence of the genus *Pseudorhapydionina* in the Late Cretaceous GCMC of this area seems to indicate the permeability between two neighboring palaeobioprovinces ("Mediterranean" Tethys and Pyrenean), favored probably by the Turonian high sea-level episode. The Pyrenean *P. bilottei* is a possible migrant from the Tethyan palaeobioprovince.

6. Conclusions

The "pseudorhapydionid" morphotypes of the La Cova deposits from the Montsec and Pedraforca thrust sheets (Santonian, Pyrenees) are attributed to the genus *Pseudorhapydionina*, and described in this paper as *P. bilottei* sp. nov. The new taxon shares with the Cenomanian species its subglobular-to-cylindrical morphology with cribrate aperture, early stage of growth with chambers planispirally arranged becoming uncoiled in the adult stage, radial septula, and lack of pillars. It differs from the Cenomanian species by its qualitative characteristics.

Prior to this work, the genus *Pseudorhapydionina* was only known from the latest Albian?-Cenomanian. Based on SIS analysis on the stratigraphical levels containing *Pseudorhapydionina bilottei* sp. nov., the age of this genus can be extended to the early Santonian, thus indicating that the genus *Pseudorhapydionina* is a probable survivor of the mid-Cretaceous GCMC across the CTB.

The new subfamily Pseudorhapydionininae is described, grouping the porcelaneous, cylindrical-to-fan-shaped or cyclical shaped foraminifera, characterized by a planispiral-involute chamber arrangement in the early stage of growth, which may become uncoiled or fan shaped-to-cyclical in the adult stage with marginal radial septula and cribrate aperture.

Acknowledgments

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5.3 Article 4

Author's contribution

Rotaloidean foraminifera from the Upper Cretaceous carbonates of Central and Southern Italy and their chronostratigraphic age.

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Rotaloidean foraminifera from the Upper Cretaceous carbonates of Central and Southern Italy and their chronostratigraphic age

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ABSTRACT

New rotaloidean foraminifera from the Upper Cretaceous shallow-water carbonates of Central and Southern Italy have been described, thus widening the knowledge on the Late Cretaceous rotaloidean foraminifera in the Central Tethyan realm. *Rotorbinella lepina* sp. nov., *Rotalispira vitigliana* sp. nov. and *R. maxima* sp. nov., belong to the family Rotaliidae (subfamilies Rotaliinae and Lockhartiinae, respectively). *Pilatorotalia pignattii* gen. nov. sp. nov. and *Neorotalia? cretacea* sp. nov. are placed in the family Pararotaliidae. Moreover, further studies are carried out on the associated *Rotalispira scarsellai* and "*Stensioeina*" *surrentina*. The age assignment of these rotaloideans has been calibrated by means of strontium isotope stratigraphy to late Santonian?-middle Campanian.

1. Introduction

The rotaloideans are a group of numerous, complex, larger (sometimes of small size) foraminifera that range from the Cenomanian (late Albian?) to recent. The known research history of the rotaloidean foraminifera started early in the 19th century with the description of *Rotalia trochidiformis* from the Lutetian of the Paris basin (Lamarck, 1804), and was subsequently improved in the second half of the past century and the present century (see, for instance, the studies by Hofker, 1951, 1971; Smout, 1954; Reiss and Merling, 1958; Reiss, 1963; Torre, 1966; Billman et al., 1980; Müller-Merz, 1980; Haynes and Whittaker, 1990; Hottinger et al., 1991; Revets, 2001; Boix et al., 2009; Benedetti et al., 2011; Benedetti and Briguglio, 2012; Sirel, 2012; Hottinger, 2014; Benedetti, 2015, among others). However, only a few of these studies refer to the Cretaceous rotaloideans. The first ones come from the chalk deposits of North-western Europe (Boreal realm; see Reuss, 1862; Hofker, 1949, 1960; among others). In the Pyrenean realm, Hottinger (1966), Tronchetti (1981), and recently Boix et al. (2009) accurately described the morphology and structure of several new genera and species. Whereas, in the Central Tethys only two species were described from the Upper Cretaceous of Southern Italy (Sorrento Peninsula), *Rotalispira scarsellai* (named *Rotorbinella scarsellai* in Torre, 1966) and "*Stensioeina*" *surrentina* Torre. Although abundant sections of diverse rotaloidean foraminifera are commonly reported from shallow carbonate platform facies in ancient and recent geological literature, such as *Rotalia* or *Rotorbinella* (Crescenti, 1969; De Castro, 1974; Chiocchini and Mancinelli, 1977; Carbone and Catenacci, 1978; Lupero Sinni and Ricchetti, 1978; Mariotti, 1982; Molinari Paganelli and Tilia Zuccari, 1987; Pirini Radrizzani et al., 1987; Lupero Sinni and Reina, 1996; Carannante et al., 1998; Tentor, 2007; Schlüter et al., 2008; Brandano and Loche, 2014, among others). The papers of Luperto Sinni (1976) and Lupero Sinni and Ricchetti (1978) are particularly interesting because they offer an extraordinarily richness of figured rotaloideans (pl. 49–54 and 60–63, respectively).

Therefore, the aim of the present work is to study the rotaloidean foraminifera present in Central and Southern Italy, particularly in the deposits of the Lepini Mounts (Central Italy) and Cava Vitigliano (Southern Italy), which provide abundant, diverse, and sometimes well preserved, rotaloidean morphotypes associated with well known porcelaneous and agglutinated foraminiferal taxa, most of them stratigraphically branded by Chiocchini et al. (2012) and Frijia et al. (2015). The studied material allowed us

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the identification of the most important and diagnostic rotaloidean architectural elements and permitting the description of five new taxa, which greatly increase the knowledge of still poorly defined group of the Late Cretaceous Global Community Maturation Cycle *sensu* Hottinger (2001) in the Central Tethys. Moreover, we precisely define the age of the beds containing the new rotaloidean foraminifera by means of strontium isotope stratigraphy, which could lead to the use of these taxa as a potential tool for biostratigraphy.

2. Geological setting, provenance of the material and methods

2.1. Central Italy

The samples were mainly collected in the Lepini Mounts which are located in the Southern part of the Latium region (Fig. 1). Lepini Mounts, together with the neighbouring Ausoni and Aurunci Mounts, create a continuous mountain range of 80 km in length, composed mainly of a thick series of Mesozoic shallow-water carbonates (Accordi, 1966). The sedimentological and biostratigraphical data of the Cretaceous deposits of the Lepini Mounts are mainly from Angelucci and Devoto (1966), Carbone and Catenacci (1978), Chiocchini and Mancinelli (1977), Chiocchini et al. (1994) and Brandano and Loche (2014). In terms of biostratigraphy, the 'Rava Santa Maria' section (see fig. 1 of Chiocchini et al., 1994; detailed in fig. 1 of Chiocchini and Mancinelli, 2001) remains one reference section not only for the Lepini Mounts, but also for the Santonian-Maastrichtian shallow-water series of Central Tethys. Moreover, the first revision of the Italian deposits containing *Keramosphaerina tergestina* (Stache), taxon erroneously assigned to the Palaeocene (Devoto, 1964), and the type-locality of the well-known genus *Accordiella conica* Farinacci come from the Lepini Mounts.

The investigated section is located on the south-western side of Monte delle Castagne (base of the section: N 41°38′49″-E 13°07′12″; top of the section: N 41°38′54″-E 13°07′23″, see also Fig. 1), which is 1.5 km South-east of the village of Gorga and 2 km South-west of the 'Rava Santa Maria' section (Monte Filaro). The section consists of around 100 m of shallow-water limestones, where some dolomitized levels alternate with foraminiferal-rich wackestone facies and rudist debris (Fig. 2). Brandano and Loche (2014) individuated a series of rudist pillarstone interbedded with cross-bedded grainstone–packstone and laminated mudstone–wackestone in this area. The deposits were interpreted formed in a shoreface setting characterised by scattered rudist constructions and bioclastic sand bars and/or floatstones. They contain an association of imperforate foraminifera and demosponge comprising *Dicyclina schlumbergeri* Munier-Chalmas (Fig. 3A), *Accordiella conica* Farinacci (Fig. 3A), *Scandonea mediterranea* De Castro (Fig. 3A) *Montcharmontia apenninica* (De Castro), *Nezzazatinella* sp. (Fig. 3B), *Murgella lata* Luperto Sinni (Fig. 3D, I), *Sarmentofascis zamparelliae* Schlagintweit et al. (Figs. 2, 3E), *Praemurgella valenciana* Luperto Sinni et al. (Fig. 3F, G), and *Keramosphaerina tergestina* (Stache) (Fig. 3H). *Rotalispira scarsellai*, "*Stensioeina*" *surrentina* and *Rotalispira maxima* sp. nov. (*Calcarinella shaubi* in Chiocchini et al., 2012) have been identified among the lamellar-perforated foraminifera. According to Chiocchini et al. (1994), the studied deposits correspond to the middle and upper part of the Radiolitids Limestone unit, which belongs to the '*Accordiella conica and Rotorbinella scarsellai*' biozone (Coniacian to lower Campanian of Chiocchini et al., 1994, 2012). Based on strontium isotope stratigraphy (SIS), Frijia et al. (2015) assigned the *K. tergestina* level in Southern Italy as corresponding to the lower Campanian.

The rotaloidean foraminifera come from 31 samples of cemented carbonate rocks labelled from 01 to 035 (Appendix I: Supplementary Data; see their distribution in Fig. 2 and some representative facies in Fig. 4A–C). More than 170 thin sections were obtained from these samples for this study. A very interesting isolated sample (labelled 057, N 41°39′26″-E 13°07′05″, see the position also in Fig. 1B; Appendix II: Supplementary Data)

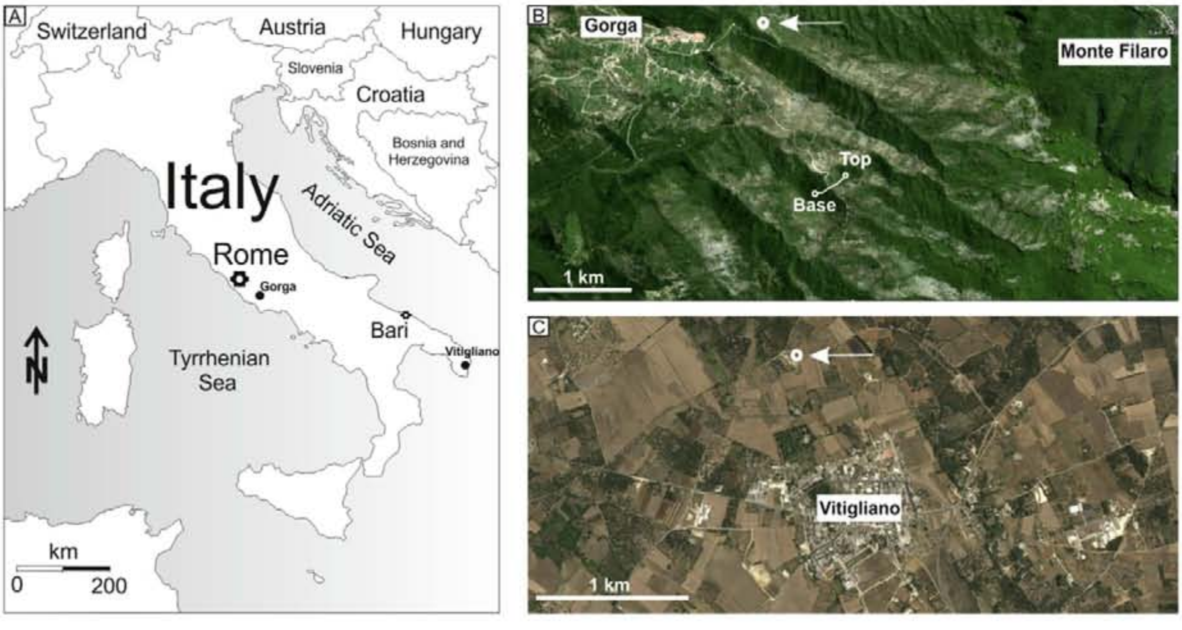

Fig. 1. A: Sampled Localities. B: Base and top of the sampled column, white arrow indicates the position of the sample 057 (PUAB 82487). C: White arrow indicates the position of the sample CC1 (PUAB 82475).

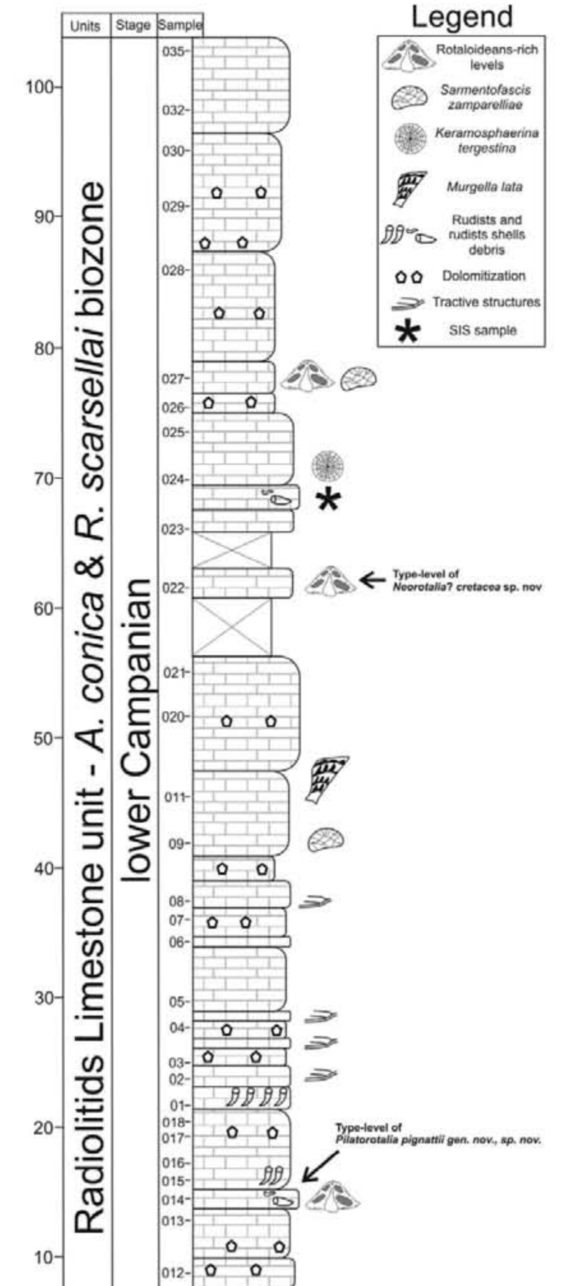

Fig. 2. Details of the sampled column from Central Italy (Lepini Mounts). Position of some type-levels is also indicated.

consisting of foraminiferal-microbialitic facies (Fig. 4D) comes from a stratigraphic level that has been correlated in the field with the upper part of the studied section. Some additional samples are from Monte Rotondo and Monte Feuci (Ausoni Mounts), as well as from Monte Filaro (Lepini Mounts) (see their position in fig. 1 of Chiocchini et al., 1994). The samples of the two former areas are from the "*A. conica* and *R. scarsellai* biozone", while the samples from the last area are from the "*Discorbidae* and *ostracoda*" biozone (see Chiocchini et al., 1994, for details).

2.2. Southern Italy

The samples from Southern Italy have been collected mainly in Cava Vitigliano (Fig. 4E, F), but an additional one is from Trentinara (see Schlagintweit et al., 2016 for localization of the area). The well-known outcrops of the Cava Vitigliano, an abandoned quarry, are located 900 m north of the Vitigliano village in the Lecce province (Salento, South-east Italy, Fig. 1C). The quarry represents an almost unique window looking to the Campanian inner/back-edge carbonate platform deposits of the Apulian platform. The outcrop, only visible in the flank of the quarry, consists of 3 m of horizontal massive limestone, characterised by abundant rudist bioclasts chaotically found as rudstone lenses. Deposits with similar lithology were named in Central Apennines as "Calcari cristallini" (Colacicchi, 1967). However, in recent times, they have been attributed to the upper part of the Santa Cesarea Limestone Unit (see stratigraphic considerations and complete lithostratigraphy in Schlüter et al., 2008).

The quarry is famous for the optimally preserved fauna of rudists that have been studied in detail (Cestari and Sirna, 1987; Guarnieri et al., 1990; Laviano and Skelton, 1992; among others). The first ones to introduce the Cava Vitigliano in the foraminiferal specialised literature were Papetti and Tedeschi (1965). They did an exhaustive study of the main microfacies, and mentioned *Cuneolina pavonia parva* Henson, *Orbitoides tissoti* Schlumberger, and a new porcelaneous genus, *Cuvillierinella salentina*. Foraminiferal description from Cava Vitigliano deposits was subsequently improved by De Castro (1990), who mentioned a rich assemblage of foraminifera including *Accordiella conica* Farinacci, *Minouxia conica* Gendrot, *Montcharmontia apenninica* (De Castro), *Pseudocyclammina sphaeroidea* Gendrot, *Cuvillierinella salentina* (*Raadshovenia salentina* in the De Castro's paper), *Pseudochubbina bruni* De Castro, *Murciella cuvillieri* Fourcade, *Orbitoides* sp., *Pseudosiderolites? vidali* (Douvillé), and the rotaloidean *Rotalispira scarsellai* and "*Stensioeina*" *surrentina*. *Rotalispira maxima* sp. nov. is also present in our samples. The age given to the ensemble of Cava Vitigliano deposits by Papetti and Tedeschi (1965) was late Santonian, but De Castro (1990) suggested a Campanian age. Schlüter et al. (2008), based on Strontium Isotope stratigraphy, restricted the age to the latest middle Campanian (see their fig. 2).

The description of the new rotaloidean foraminifera from Cava Vitigliano is based on one sample of cemented carbonate rock labelled CC1 (Appendix III: Supplementary Data) collected in the north-eastern side of the quarry (N 40°02′50″-E 18°24′35″). The sample was fully used up, 22 thin sections were obtained from which about 60 sections (oriented and random) have been studied. A further sample comes from Trentinara (sample P-1023 in fig. 6 of Frijia et al., 2015) from which one axial section has been obtained. In this last area the level containing the new rotaloidean here described as *Rotalispira maxima* sp. nov. was dated by means of strontium isotope analysis as early Campanian (Frijia et al., 2015).

A set of specialised terms were used for the structural analysis of the rotaloidean foraminifera (see Hottinger, 2006; 2014). The sections have been named according to Billman et al. (1980) and Hottinger (2014). All the specimens are illustrated with a fixed enlargement in order to facilitate the comparison of the new taxa with other previously described taxa. We use the parameter D/H (test diameter against test height) for characterize the new species.

The specimens presented in this paper have been deposited in the Palaeontological collection of the Department of Geology (Palaeontology) of the *Universitat Autònoma de Barcelona* (PUAB 82475–82487), and in the Micropalaeontological collection of the Italian Geological Survey/ISPRA (Institute for Environmental Protection and Research, Rome) with thin sections labelled IS-1443, IS-A1051, IS-A957.

3. Systematic micropalaeontology

Phylum FORAMINIFERA (Orbigny 1826) Pawlowski et al., 2013
Class GLOBOTHALAMEA Pawlowski et al., 2013
Order ROTALIIDA Delage and Hérouard, 18960
Remarks. Phylum, class and order are from Pawlowski et al., 2013, and they are not discussed in this paper.

Superfamily Rotaloidea Ehrenberg, 1839, revised Hottinger, 2014

Remarks. Hottinger (2014) described the superfamily Rotaloidea (Rotaliacea in the Hottinger's work) as "Shell walls lamellar-perforate; chamber arrangement trochospiral; foramen single, in interiomarginal position; folium and umbilical plate present; face ventral" but in our work, we take Rotaloidea in a broad sense in order to include the representatives of the Pararotaliidae.

Family Rotaliidae Ehrenberg, 1839, revised Hottinger 2014

Remarks. The family Rotaliidae has been recently revised by Hottinger (2014) and re-defined as: bi-lamellar-perforate trochospiral shells with single intercameral foramen in an intermarginal position. Dorsal side evolute and ventral side involute. Presence of folium and umbilical plate. The umbilicus filled with a single axial pile or columellar filling. Spiral and intraseptal interlocular spaces transformed into spiral and intraseptal canals.

Subfamily Rotaliinae Ehrenberg 1839, revised Hottinger 2014

Remarks. This subfamily, re-defined by Hottinger (2014), is characterised by the absence of dorsal ornamentation and the umbilical spaces subdivided by free-standing piles. The foliar suture is marked by a notch.

Genus *Rotorbinella* Bandy 1944
Type species: *Rotorbinella colliculus* Bandy, 19440
Remarks. The main characteristics of this genus are: the small to medium sizes, the umbilical plug, the small to medium wide, and slightly oblique, folia, and the intraseptal and umbilical open interlocular spaces. For further details see Revets (2001), Boix et al. (2009) and Hottinger (2014). The genus *Rotorbinella*, with the Cenomanian species *R. mesogeensis* (Tronchetti) appeared in the fossil record probably in the late Albian (Consorti et al., 2014; Hottinger, 2014).

Rotorbinella lepina sp. nov.
Fig. 5

1976 *Alabamina? cretacea* Hofker – Luperto Sinni: Pl. 50, figs 6–7.
1976 *Rotalia saxorum* d'Orbigny – Luperto Sinni: Pl. 49, figs 6–10.
1978 *Rotalia saxorum* d'Orbigny – Luperto Sinni and Ricchetti: Pl. 61, figs 1–4.
2003 *Rotalia reicheli* Hottinger – Polavder: figs 3.13, 3.14

Holotype. Specimen 'PUAB 82476', figured in Fig. 5A.
Type locality. Monte delle Castagne, Lepini Mounts, Lazio, Central Italy. See reference in the column (Fig. 2).
Type horizon. Middle-upper part of the Radiolitidae Limestone unit, lower Campanian.
Etymology. The specific name is given from Lepini Mounts
Number of studied specimens. 35
Diagnosis. medium-sized, high trochospiral shell. The dorsal side is highly convex, unornamented and perforated by pores of wide calibre. Chamber walls are particularly thick. The umbilical side is flat to slightly convex, and occupied by a massive plug surrounded by a narrow spiral interlocular space transformed into a spiral canal. The periphery is acute with a more or less pronounced imperforate keel. Folia are relatively wide and imperforate and never overlap the central part of the plug. The foliar chamberlet is separated from the main chamber lumen by the umbilical plate, which forms a rectilinear sutural notch. An interlocular intraseptal canal is present along the septa, which is slightly curved and thickens near the aperture. The trochospire consists of up to 3 whorls of trapezoidal chambers. There are at least 8–9 chambers in the last whorl. The average diameter of the proloculus is 30–35 μm. Shell diameter varies from 0.9 to 1 mm, while the height varies from 0.63 to 0.71 mm. The average D/H ratio is 1.42. Dimorphism not observed.
Differential diagnosis. *Rotorbinella lepina* n. sp. differs from the Cenomanian *R. mesogeensis* in its conical shape (high trochospire) and dimensions, which are 2–2.5 times wider. *Rotorbinella lepina* has similar morphology to *R. campaniola* Boix et al., from the upper Coniacian–lower Campanian of the Pyrenees, but this species has less chambers per whorl; six chambers in the last whorl for *R. campaniola*, and 8–9 for *R. lepina*, respectively. The sutural notch of *R. lepina* is straight, compared with the curved sutural notch of *R. campaniola*. Folia of *R. lepina* are wider and more inclined than those of *R. campaniola*.
Associated fauna. *Rotalispira scarsellai*, *Rotalispira maxima* sp. nov., *Montcharmontia apenninica*, *Dicyclina schlumbergeri*, *Scandonea mediterranea*, *Accordiella conica*, *Keramosphaerina tergestina*, *Murgella lata*, *Praemurgella valenciana*.
Biostratigraphical and Geographical distribution. This species is present in the upper Santonian?-lower Campanian of Central Italy (this work). Moreover, it was reported from the Campanian of the Apulian platform (Southern Italy, Luperto Sinni, 1976; Luperto Sinni and Ricchetti, 1978) and from the Campanian of Serbia (Western Vardar Zone, Polavder, 2003). See the synonym list for details.

Subfamily Lockhartiinae Hottinger, 2014

Remarks. According to Hottinger (2014), the subfamily Lockhartiinae is characterised by low trochospiral shells with long and oblique folia supported by piles covering large parts of the umbilicus.

Genus *Rotalispira* Hottinger, 2014
Type-species: *R. scarsellai* (Torre, 1966)

Description. According to Hottinger (2014), the genus *Rotalispira* is characterised by coarsely perforated shells with angular and keeled periphery. Hemispherical outline. Umbilicus often without or with few foliar piles, but filled with perforate, very long folia superposed like the blades of a propeller. There is a wide spiral canal. For more information see Hottinger (2014).
Remarks. The lack of umbilical plug and the presence of oblique folia supported by piles easily distinguish *Rotalispira* from *Rotorbinella*. From the Upper Cretaceous of the Western Tethys, the genus *Pyrenerotalia* Boix et al. shows a smooth dorsal surface and funnels in the umbilical side, characteristics not present in *Rotalispira*. The biconvex lens-shaped *Iberorotalia* Boix et al. differs from *Rotalispira* in having a composite umbilical plug fused with folia. *Rotalispira* differs from the Cretaceous representatives of the genus *Pararotalia* because this last genus possesses a visible tooth-plate, a large umbilical plug, and an acute periphery.

Rotalispira vitigliana sp. nov.
Fig. 6A–L, 6N–O

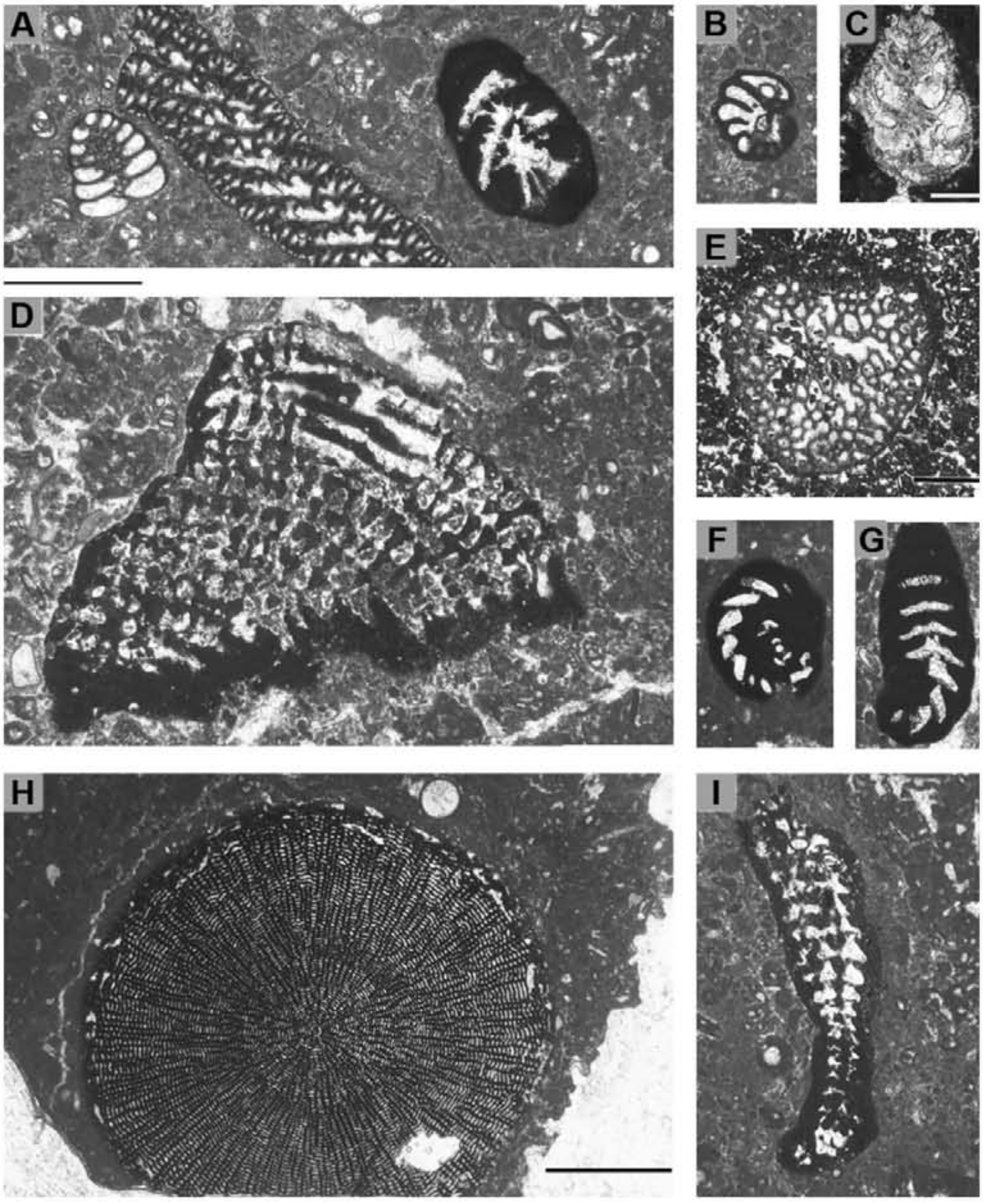

Fig. 3. Foraminifera from the sampled column, Lepini Mount. Scale bar 1 mm except in C, E, H. A. From left to right: *Accordiella conica*, *Dicyclina schlumbergeri*, *Scandonea mediterranea*. B. *Nezzazatinella* sp. C. Undetermined high trochospire rotaloidean, the same form has been cited by Lupero Sinni and Ricchetti (1978) as *Allomorphina*? Scale bar 0,2 mm. D. *Mugella lata*. E. *Sarmentofascis zamparelliae*, scale bar 1 mm. F, G. *Praemurgella valenciana*. H. *Keramosphaerina tergestina*, scale bar 2 mm. I. *Murgella lata* in longitudinal section.

Holotype. Specimen 'PUAB 82475', figured in Fig. 6A.
Type locality. Quarry at the northern side of Vitigliano village, Salento, Puglia, SE Italy.
Coordinates. N 40°02′50″–E 18°24′35″.
Type horizon. Upper part of the Santa Cesarea Limestone unit, middle Campanian.
Etymology. The specific name is given from Vitigliano, the closest village to the locality type.
Diagnosis. Small to medium sized shell with the architectural style of *Rotalispira*. Chambers are low trochospirally arranged and gradually increase in size. Rounded periphery. Dorsal side almost flat and ornamented. Ventral side plano-concave. Dimorphism not observed. The new species has at least 3 spiral whorls with 10 chambers in the last whorl. Septa, slightly curved, thicken at their base. Each folium produces a more or less sharp foliar pile in axial direction. Proloculus sizes between 40 μm and 60 μm. Chamber height is almost double its width. The D/H ratio varies from 1.8 to 2.2. The calibre of the coarse pores is 15–20 μm.
Differential diagnosis. *Rotalispira vitigliana* diameter is approximately 1.5 times bigger than *R. scarsellai*. The trochospire is high in

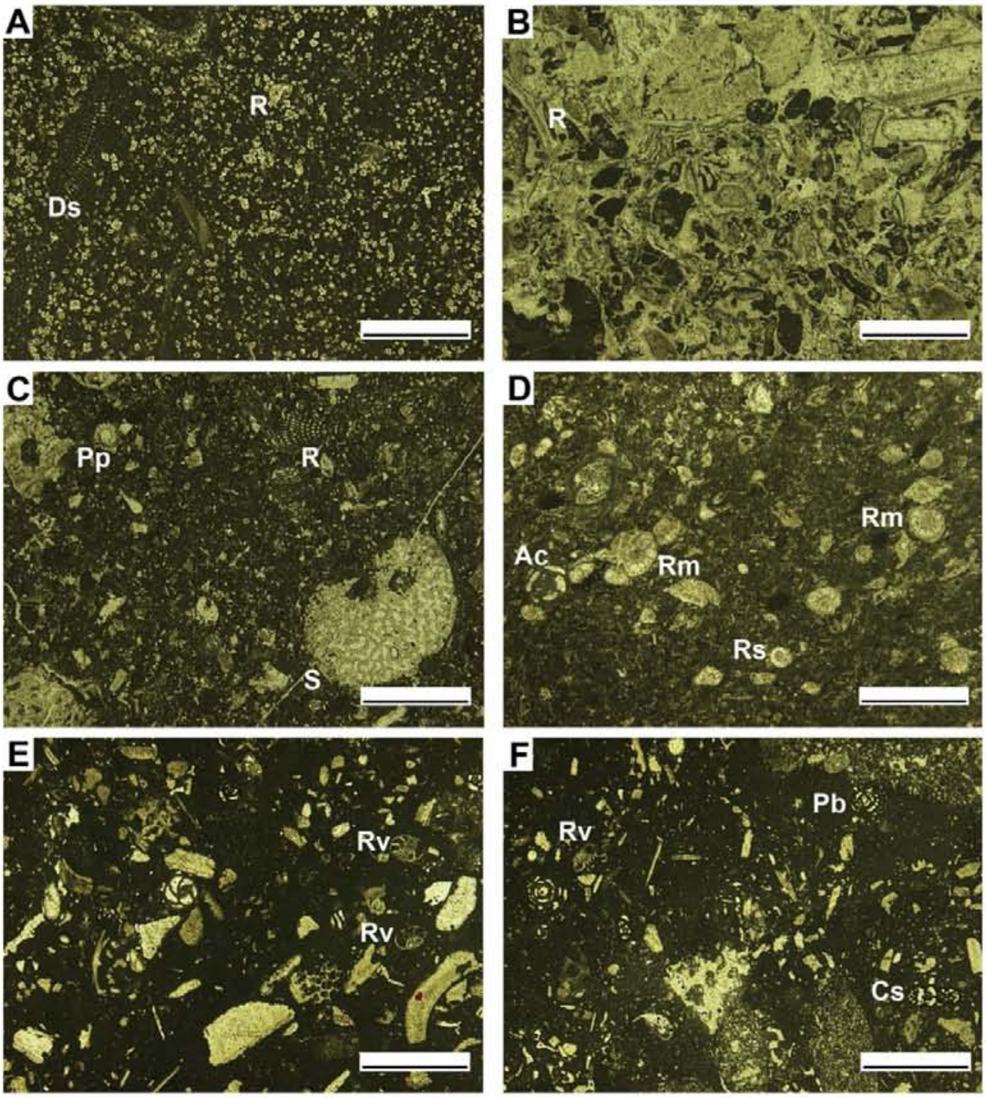

Fig. 4. Rotaloideans-bearing facies. Scale bar 2 mm for all figures. A. Dolomitized wackestone with *Dicyclina* (D) and rotaloideans (R). B. Miliolids and rudist shells grainstone with rotaloidean (R). C. Packstone with *Pilatorotalia pignattii* gen. nov., sp. nov. (Pp), rotaloidean (R) and *Sarmetofascis zamparelliae* (S). D. Facies representing a foraminiferal-microbial environment with *Accordiella conica* (Ac). Note the differences in size difference between *Rotalispira maxima* sp. nov. (Rm) and *Rotalispira scarsellai* (Rs). E. Packstone with *Rotalispira vitigliana* sp. nov. (Rv) and rudist fragments. F. Packstone with *R. vitigliana* sp. nov. (Rv), *Cuvillierinella salentina* (Cs) and *Pseudochubbina bruni* (Pb). A–D. From Lepini Mounts. E, F From Cava Vitigliano. A: sample 010 (PUAB 82476); B: sample 014 (PUAB 82478); C: sample 027 (PUAB 82483); D: sample 057 (PUAB 82487); E, F: sample CC1 (PUAB 82475).

R. scarsellai while in *R. vitigliana* is low-to flat. The shell elements (wall, folia, umbilical plate) are thicker in *R. scarsellai* than in *R. vitigliana.* Umbilical space in *R. scarsellai* is almost completely filled by folia, while in *R. vitigliana* folia are more spaced between them. Umbilical piles maybe fused to each other in *R. scarsellai*, while in *R. vitigliana* umbilical piles are distinctly isolated. Umbilical space is approximately 2 times wider in *R. vitigliana*, and its keel is less pronounced compared with *R. scarsellai.*

Associated fauna. *Accordiella conica, Pseudochubbina bruni, Minouxia conica, Montcharmontia apenninica, Nummofallotia apula, Orbitoides* sp, *Pseudosiderolites*? *vidali, Cuvillierinella salentina, Rotorbinella lepina* sp. nov, *Rotalispira scarsellai*, "*Stensioeina*" *surrentina.*

Biostratigraphical and geographical distribution. middle Campanian of the Apulian platform (this work) and Central Italy in association with *Cuvillierinella salentina* (Maria Rita Pichezzi, pers. comm.).

Rotalispira scarsellai (Torre, 1966)
Fig. 6M

1966 *Rotorbinella scarsellai* n. sp. – Torre: p. 422, pl. 1, figs. 1–8, pl. 2, Fig. 10.
1972 *Rotorbinella scarsellai* Torre – Bignot: pl. 7, fig. 6.
1977 *Rotorbinella scarsellai* Torre – Chiocchini and Mancinelli: pl. 40, figs. 1, 2.

1976 *Rotorbinella scarsellai* Torre – Luperto Sinni: pl. 52, figs. 1–5.
1976 *Rotorbinella* sp. – Luperto Sinni: pl. 52, figs. 6,7.
1976 *Stomatorbina?* sp. – Luperto Sinni: pl. 53, figs. 8–10.
1978 *Rotalia viennoti* Greig – Luperto Sinni and Ricchetti: pl. 60, figs. 2, 3
1978 *Rotorbinella scarsellai* Torre – Luperto Sinni and Ricchetti: pl. 62, figs. 5, 6
1978 *Stomatorbina?* sp. – Luperto Sinni and Ricchetti: pl. 62, figs. 12–14
1978 *Stensioeina surrentina* Torre – Luperto Sinni and Ricchetti: pl. 62, figs 3, 11
1990 *Rotorbinella scarsellai* Torre – Gušić and Jelaska: pl. 20, fig. 1.
1994 *Rotorbinella scarsellai* Torre – Chiocchini et al.: pl. 22, figs. 6,7,14,15.
2006 *Rotorbinella scarsellai* Torre – Tasli et al.: fig. 7W.
2007 *Rotorbinella scarsellai* Torre – Tentor: fig. 7C.
2008 *Rotorbinella scarsellai* Torre – Chiocchini et al.: pl. 30, fig. 1.
2008 *Rotorbinella scarsellai* Torre – Checchoni et al.: pl. 1, figs. 11.
2008 *Stensioeina surrentina* Torre – Schlüter et al.: fig. 4G.
2012 *Rotorbinella scarsellai* Torre – Chiocchini et al.: Pl 132, figs. 1–8.
2014 *Rotalispira scarsellai* (Torre) – Hottinger: pl. 5.1
2015 *Rotorbinella scarsellai* Torre – Frijia et al.: fig. 8G.
2015 *Rotalispira scarsellai* (Torre) – Schlagintweit et al.: fig. 6A.

For the description of this species see Torre (1966) and Hottinger (2014).

Biostratigraphical and geographical distribution. This species has been largely reported in the Coniacian–Campanian deposits of Italy (Southern Alps, Central and Southern Apennines, Apulian platform), and also in Croatia, Albania, Greece and Turkey (see synonymy list for references). In our study it is reported from the upper Santonian?-lower Campanian of the Lepini Mounts and middle Campanian of Cava Vitigliano. *Rotalispira scarsellai* has never been reported in the Pyrenees.

Rotalispira maxima sp. nov.

Figs. 7, 8

1972 *Stensioina surrentina* Torre – Bignot pl. 16, Fig. 19 – Note: magnification might not be correct.
1976 *Pseudorotalia?* shaubi Hottinger – Luperto Sinni: pl 50, figs. 1, 4, 5, 8.
1976 *Pararotalia tuberculifera* (Reuss) – Luperto Sinni: pl. 51 figs. 5, 7, 8.
1978 *Rotalia viennoti* Greig – Luperto Sinni and Ricchetti: pl. 60, figs. 1, 4, 7–10.
2008 *Rotorbinella scarsellai* Torre – Checchoni et al.: pl. 1, fig. 12.
2012 *Calcarinella shaubi* (Hottinger) – Chiocchini et al.: pl. 139, figs. 1–5.

Holotype. Specimen 'PUAB 82487', figured in Fig. 8C.
Type locality. Lepini Mounts, Lazio, Central Italy.
Coordinates. N 41°39′26″-E 13°07′05″.
Type horizon. Middle-upper part of the Radiolitids Limestone unit, lower Campanian.
Etymology. The specific name is given due to the large dimensions of the new species.
Number of studied specimens. 43

Diagnosis. Medium to large sized ornamented *Rotalispira.* It is composed of at least three trochospiral whorls consisting of 11–13 chambers in the last whorl. Chambers gradually increase in size throughout ontogeny. Chamber periphery keeled. Dorsal side slightly convex, ventral side plano-concave. Septa slightly dorsally curved. Dimorphism not observed. Proloculus diameter is around 88 μm. Shell diameter is 1.2–1.3 mm, while shell thickness is about 0.8/0.9 mm; the D/H ratio is almost 1.5. Coarse pores are about 18 μm in diameter. The umbilical side hosts very long and markedly oblique folia, sometimes heavily bent at the contact with foliar plies. Specimens exhibit strong ornamentation in both sides. The dorsal side is represented by thick spikes and by densely packed foliar piles in the ventral side.

Remarks. Luperto Sinni and Ricchetti, 1978 also recognised foliar piles (*pilastri* in their work) in the umbilical position, and a strong ornamentation characterising the dorsal side of the shell in their "*Rotalia viennoti*". The strong umbilical ornamentation produced by foliar piles may apparently generate funnels.
Differential diagnosis. Shells of *R. maxima* are distinguishable compared to their Cretaceous allies by their bigger size. Furthermore, the umbilical area of *R. maxima* is densely occupied by folia and foliar piles, while *R. vitigliana* leave more empty space between two successive folia. In *R. scarsellai* the umbilical area is reduced and the trochospire is higher with respect to those of *R. maxima.* Shell diameter of *R. maxima* is almost the double compared with that of *R.* scarsellai. Besides, the lack of tooth-plate easily distinguish *R. maxima* from *Pararotalia tuberculifera,* while *Calcarinella shaubi* (Hottinger) has multiple apertures.
Associated fauna. Rotalispira scarsellai, Rotorbinella lepina sp. nov., *Montcharmontia apenninica, Dicyclina schlumbergeri, Scandonea mediterranea, Accordiella conica, Keramosphaerina tergestina, Murgella lata, Praemurgella valenciana.*
Biostratigraphical and Geographical distribution. This species is present in the lower-middle Campanian of Central and Southern Apennines (this work), and from the Upper Cretaceous of Apulian platform (Luperto Sinni and Ricchetti, 1978; Checconi et al., 2008). Fleury (1980) referred some *Pseudorotalia? shaubi* of Luperto Sinni (1976) to the Upper Cretaceous of Greece, while Bignot (1972) showed a specimen from Istria.

"Stensioeina" surrentina Torre, 1966

Fig. 9A–G

1978 *Stensioeina surrentina* Torre – Luperto Sinni and Ricchetti: pl 63, figs. 1–2.
2012 *Stensioeina surrentina* Torre – Chiocchini et al.: pl. 137, figs 1–6.

Remarks. Torre (1966) described, using mostly isolated matrix-free specimens from the Upper Cretaceous of the Sorrento Peninsula, a rotaloidean foraminifera characterized by "dorsally keeled, possessing spikes and probably with a large intraseptal interlocular space (defined as double septa)", but details on the canal system and the umbilical architecture are missing in the original description. This new rotaloidean has been attributed by Torre (1966) to the genus *Stensioeina* Brotzen, and erected as *S. surrentina.* The re-study of the specimens figured by Torre (1966) and our samples from Central Italy and Cava Vitigliano reveal the presence of folia, foliar piles umbilical plate and intraseptal interlocular space in *S. surrentina.* These elements are typical of the representatives of the Rotaliidae family (probably Lockhartiinae subfamily) but not of *Stensioeina* (see for details the revision of the genus by Dubicka and Peryt, 2014). However, has not been possible describe a new genus due to the scarcity of the material at our disposition.
Biostratigraphical and Geographical distribution. This species is present in the lower Campanian of Lepini Mounts and in the middle Campanian of Cava Vitigliano (this work). Further data on the

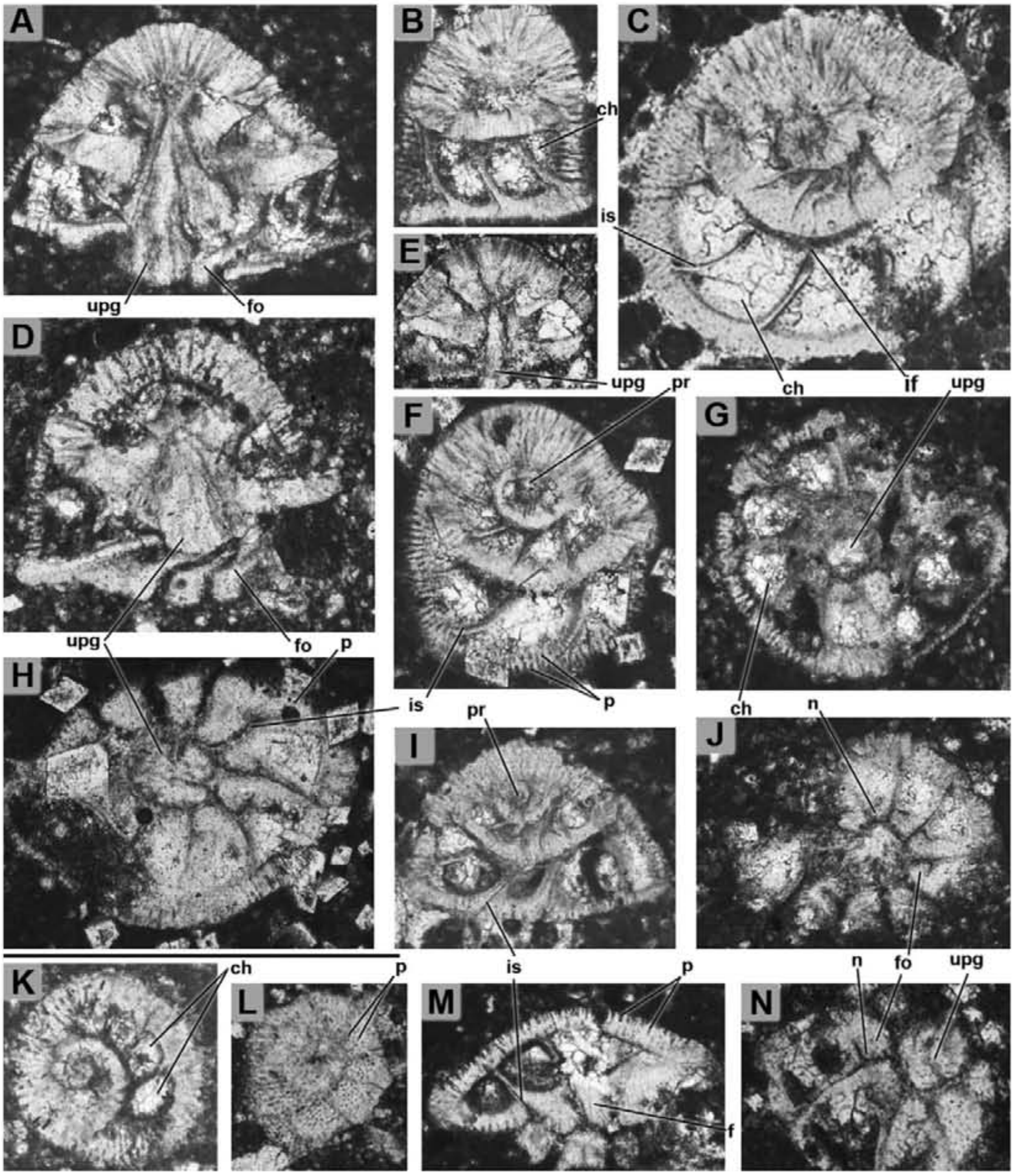

Fig. 5. *Rotorbinella lepina* sp. nov. from Lepini Mounts. Scale bar 1 mm for all figures. A. Holotype, axial section (PUAB 82476 LP01). B. Tangential section (PUAB 82480 LP01). C. Oblique section (PUAB 82484 LP02). D. Tangential section showing umbilical plug and folia (PUAB 82476 LP04). E. Axial section (PUAB 82476 LP07). F. Oblique centred section (PUAB 82480 LP01). G. Transversal section of the umbilical side (PUAB 82476 LP05). H. Tangential section of the umbilical side, note folia and central plug (PUAB 82480 LP02). I. Oblique section showing proloculus (PUAB 82483 LP08). J. Transversal slightly oblique section of the umbilical side, note folia (PUAB 82476 LP02). K, L. Tangential sections of the dorsal side (PUAB 82476 LP03 and LP06 respectively). M, N. Tangential sections showing plug surrounded by folia (PUAB 82476 LP01 and LP09 respectively)., ch: chamber lumen, fo: folia if: intercameral foramen, is: intraseptal interlocular canal, n: notch p: pore, pr: proloculus, upg: umbilical plug.

presence of this genus come from the Upper Cretaceous of Sorrento peninsula (Torre, 1966), and from the Santonian of Aurunci Mounts (Chiocchini et al., 2012).

Differences. "*Stensioeina*" *surrentina* from Lepini Mounts are bigger with respect those from Cava Vitigliano. These differences fall in the range of variability furnished by Torre (1966), but more detailed investigations are needed to confirm the presence of variability within the whole population due to age or ecological factors.

Family Pararotaliidae Reiss, 1963

Remarks. After Reiss (1963), complemented by Hottinger et al. (1991), Revets (1993) and Hottinger (2014) the family Pararotaliidae is characterised by bi-lamellar-perforate trochospiral

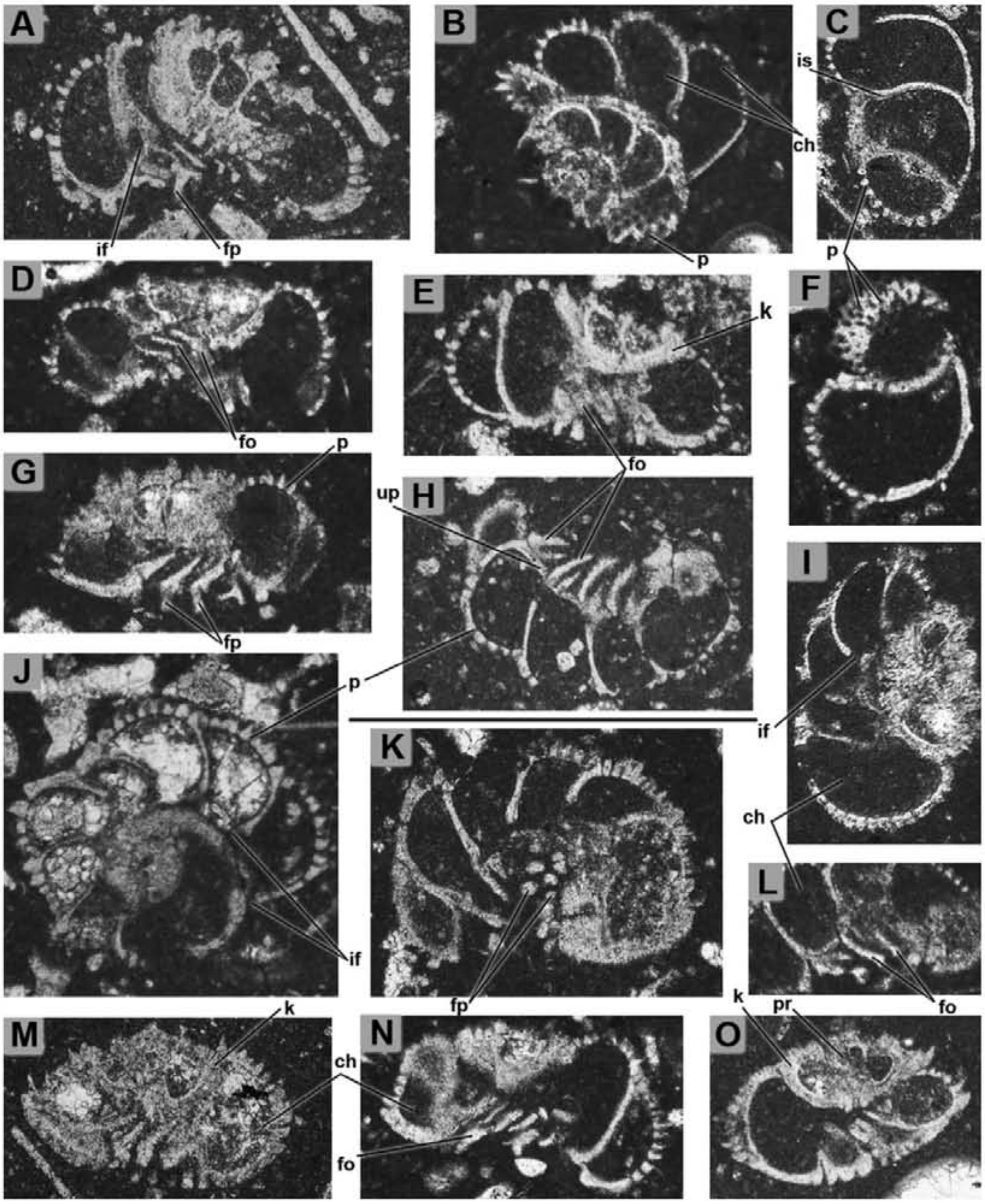

Fig. 6. *Rotalispira vitigliana* sp. nov. from Cava Vitigliano. Scale bar 1 mm, all figures are referred to the sample CC1 (PUAB 82475). A. Holotype, oblique section showing intercameral foramen and foliar piles (LP01). B. Oblique slightly transverse section (LP01). C. Tangential section showing three chambers (LP07). D, E. Close to the axial sections (LP09 and LP11 respectively). F. Tangential section showing two chambers (LP05). G. Close to the axial section, note vertical foliar piles and oblique folia (LP01). H. Oblique transversal section showing umbilical plate and folia (LP08). I. Oblique section (LP13). J. Transversal section (LP03). K. Transversal section displaying folia and foliar piles (LP10). L. Detail of folia from a transversal section (LP12). M. *Rotalispira scarsellai* (Torre) in axial section (LP02). N. Close to the axial section, note oblique folia (LP02). O. Oblique centred section (LP10). ch: chamber lumen, fo: folia, fp: foliar pile, if: intercameral foramen, is: intraseptal interlocular canal, k: keel, p: pore, pr: proloculus, up: umbilical plate.

shells with single interiomarginal aperture, umbilical flap and tooth-plate separating the chamber lumen from the interlocular space. Dorsal side evolute, ventral side involute. The umbilicus shows plugs, piles or columellar structures, but lacks folia. Canal system consisting of intraseptal and spiral umbilical canals; the last one is formed by interconnected tooth-plates. They may have enveloping canal system produced by secondary lamination (see Hottinger et al., 1991, for details).

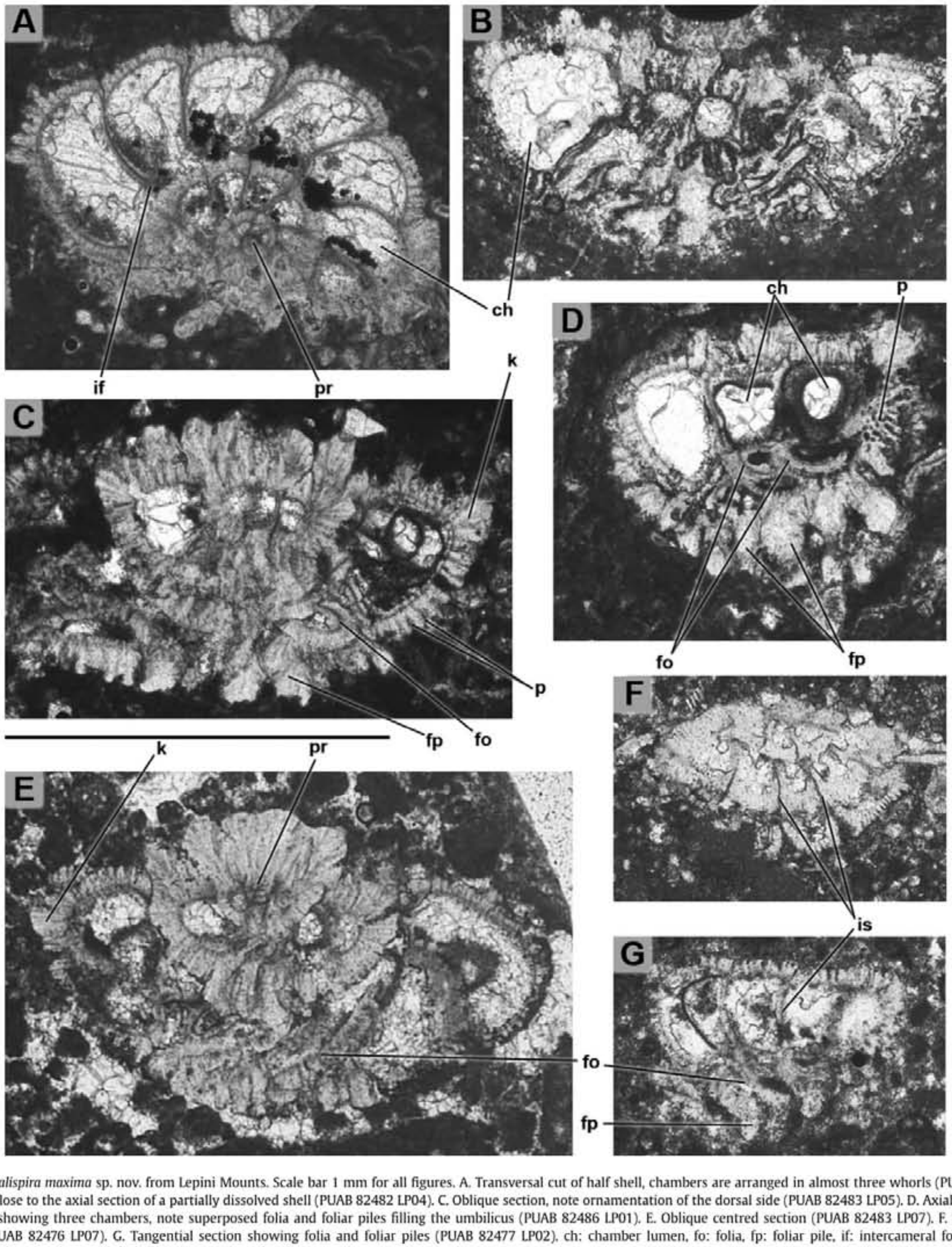

Fig. 7. *Rotalispira maxima* sp. nov. from Lepini Mounts. Scale bar 1 mm for all figures. A. Transversal cut of half shell, chambers are arranged in almost three whorls (PUAB 82482 LP05). B. Close to the axial section of a partially dissolved shell (PUAB 82482 LP04). C. Oblique section, note ornamentation of the dorsal side (PUAB 82483 LP05). D. Axial section of half shell showing three chambers, note superposed folia and foliar piles filling the umbilicus (PUAB 82486 LP01). E. Oblique centred section (PUAB 82483 LP07). F. Tangential section (PUAB 82476 LP07). G. Tangential section showing folia and foliar piles (PUAB 82477 LP02). ch: chamber lumen, fo: folia, fp: foliar pile, if: intercameral foramen, is: intraseptal interlocular canal, k: keel, p: pore, pr: proloculus.

Subfamily Pararotaliinae Reiss, 1963

Remarks. The suprageneric position of the new taxon described below, *Pilatorotalia* n. gen., remain difficult to assess. However, the presence of a distinctive tooth-plate and the lack of folia induce us to include the new genus into the family Pararotaliidae. To propose a coherent classification of the family Pararotaliidae into subfamilies is not the scope of this work and will be taken in account in the future.

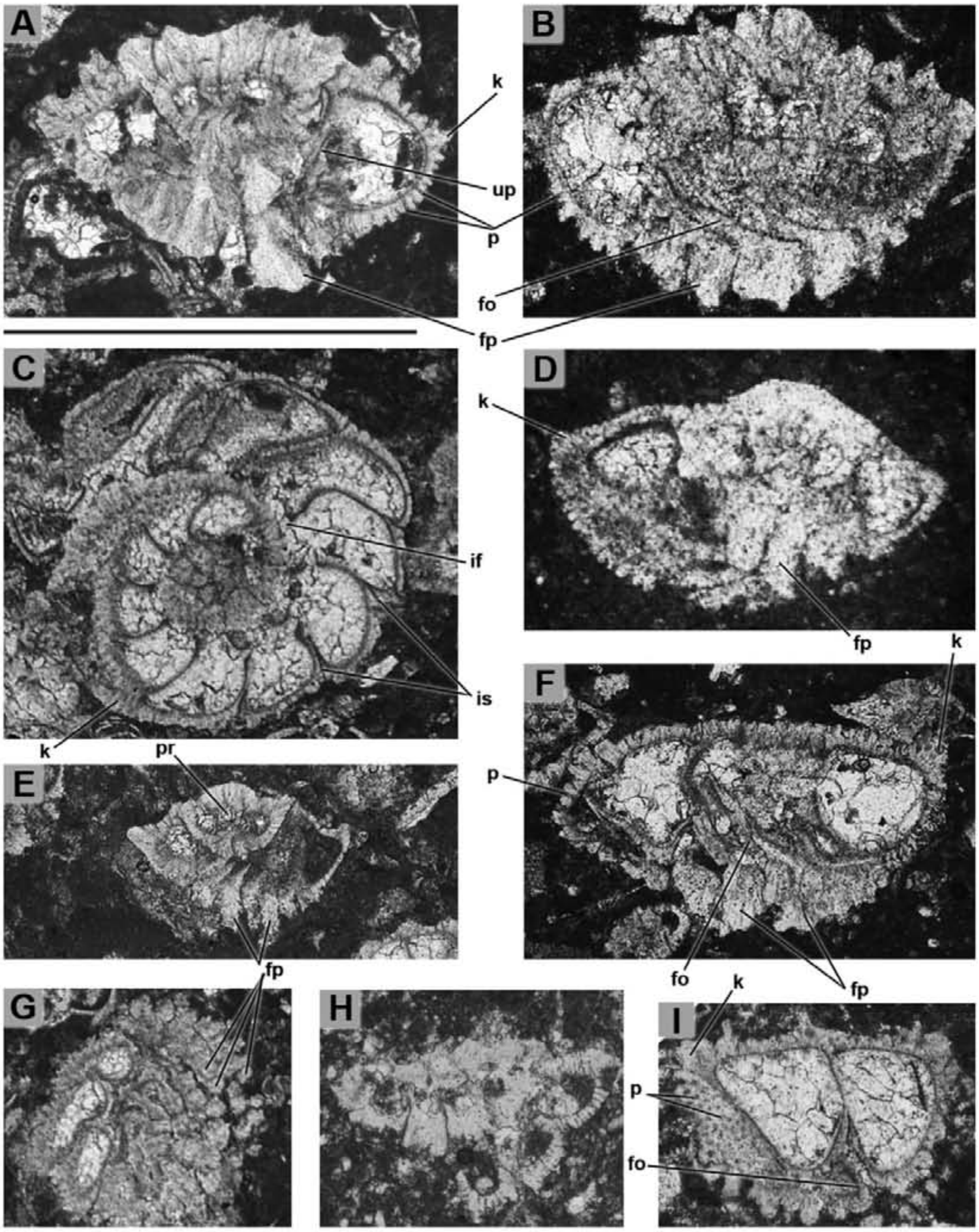

Fig. 8. *Rotalispira maxima* sp. nov. Scale bar 1 mm for all figures. A. Axial section (PUAB 82482 LP01). B. Axial section, note wide folia running slantwise within the umbilicus and producing vertical foliar piles at their inner end (P-1023). C. Holotype. Transversal section of the lasts 1,5 whorls. Some septa (lower side) are broken (PUAB 82487 LP01). D. Axial section from Monte Feuci (IS-A1051). E. Axial section of a specimen composed by 2 whorls (PUAB 82487 LP01). F. Tangential section, note strongly curved folia and huge foliar piles (PUAB 82483 LP01). G. Tangential section of the umbilical side, note umbilicus almost totally filled by foliar piles (PUAB 82487 LP01). H. Tangential section (PUAB 82481 LP02). I. Two chambers are here cut tangentially, note foliar bending (PUAB 82481 LP01). ch: chamber lumen, fo: folia, fp: foliar pile, if: intercameral foramen, is: intraseptal interlocular canal,, k: keel, p: pore, pr: proloculus up: umbilical plate.

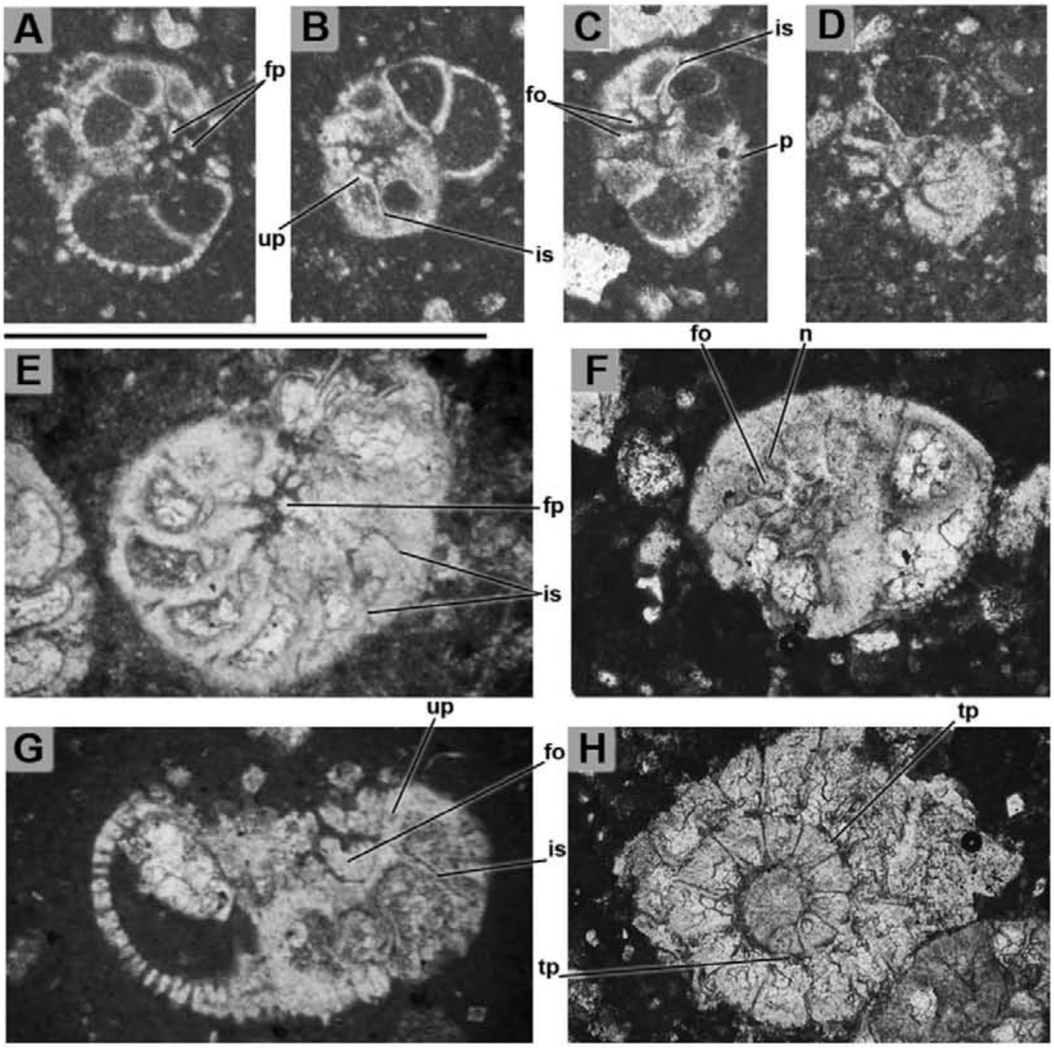

Fig. 9. A–G: "*Stensioeina*" *surrentina* Torre. A–D: from Cava Vitigliano, E: from Aurunci Mounts, G: from Monte Filaro (Lepini Mounts). H: *Pilatorotalia piagnattii* gen. nov., sp. nov. Scale bar 1 mm for all figures. A–D. Transverse and tangential sections of umbilical sides, showing folia, umbilical plate and foliar piles (PUAB 82475 LP07,04,09). E. Transverse section of the umbilical side with foliar piles (IS-A957). F. Tangential section of the umbilical side, note the presence of small folia (PUAB 82481 LP01). G. Oblique section showing large intraseptal interlocular space, umbilical plate and the adjoining folia (IS-1443). H. Transverse section of the dorsal side, here tooth-plate develop between two successive whorls constraining the spiral canal (PUAB 82483 LP01). fo: folia, fp: foliar pile, if: intercameral foramen, is: intraseptal interlocular canal, p: pore, tp: tooth-plate, up: umbilical plate.

Genus *Pilatorotalia* gen. nov.
Species-type *Pilatorotalia pignattii* sp. nov.

Derivatio nominis. The generic name is given from the presence of huge piles (*pilates* in Latin) in the umbilical side of the shell.

Diagnosis. Medium-sized, trochospiral biconvex shell. Dorsal side smooth and free of ornamentation. Ventral side largely occupied by fused piles producing an umbilical mass crossed by numerous vertical funnels. Trapezoidal chambers are higher than wider, and have an acute periphery. Ventral sutures are radial and feathered, especially marked at its proximal part at the contact with the piles. Canal system composed of intraseptal interlocular spaces and a tubular spiral interlocular space restricted by the tooth-plate. A reticulate canal network (funnels) is also present crossing the umbilical mass. Dimorphism has not been observed. No enveloping canals are observed.

Differential diagnosis. *Pilatorotalia* gen. nov. differs from *Pararotalia* Le Calvez in the un-ornamented dorsal side and the ventral sutural interlocular space divided by piles. This latter characteristic is shared with the genus *Neorotalia* Bermudez but this genus has pustules in both sides like *Pararotalia* and may develop an enveloping canal system.

Pilatorotalia pignattii sp. nov.
Figs. 9H, 10

1978 *Pararotalia*? sp. – Luperto Sinni and Ricchetti: pl. 62 figs. 10, 15, 16.

Holotype. Specimen 'PUAB 82478', figured in Fig. 10A.
Type locality. Monte delle Castagne, Lepini Mounts, Lazio, Central Italy. See reference in the column (Fig. 2).
Type horizon. Middle-upper part of the Radiolitids Limestone unit, lower Campanian.
Etymology. The specific name is given in honour of Prof. J. S. Pignatti (Rome), a recognised expert on the systematic and ecology of fossils and living benthic foraminifera.
Number of studied specimens. 34

Diagnosis. medium-sized, lamellar perforate trochospiral shell. Low convex dorsal side un-ornamented and showing lamellar thickening due to the formation of successive lamellae during ontogeny. The periphery of the shell is angular and keeled. Ventral side convex and largely occupied by piles and funnels. The massive funnelled plug is surrounded by a spiral interlocular space (spiral canal). The trochospire consists of 2–2.5 whorls and is composed by slightly rectangular chambers, which are higher than wider. There are at least 12–13 chambers in the last whorl. The small proloculus is 30 μm in diameter. Shell diameter varies from 1.1 to 1.2 mm, while the height varies between 0.71 and 0.77 mm; the average D/H ratio is approximately 1.46. The intraseptal interlocular space is present along the straight septa. The spiral canal is restricted by the successive tooth-plates.
Associated fauna. *Rotalispira scarsellai*, *Rotalispira maxima* sp. nov., *Rotalispira vitigliana* sp nov., *Rotorbinella lepina* sp. nov., *Montcharmontia apenninica*, *Dicyclina schlumbergeri*, *Scandonea mediterranea*, *Accordiella conica*, *Keramosphaerina tergestina*, *Murgella lata*, *Praemurgella valenciana*.
Biostratigraphical and Geographical distribution. This species is present in the upper Santonian?-lower Campanian of Lepini Mounts and in the Upper Cretaceous of Apulian platform (Lupero Sinni and Ricchetti, 1978).

Genus *Neorotalia* Bermudez, 1952
Species type: *Rotalia mexicana* Nuttall, 1928

Remarks. this heavily ornamented rotaloidean, described from the Oligocene deposits of America, has been considered synonymous with *Pararotalia* Le Calvez by Loeblich and Tappan (1987). However, Hottinger et al. (1991) retained *Neorotalia* as a genus distinct from *Pararotalia* based on the presence of an enveloping canal system and a divided ventral sutural interlocular space in the latter. The similarities and differences between *Neorotalia* and the recently described *Granorotalia* and *Ornatorotalia* from the Palaeogene of Italy (Benedetti et al., 2011) included in the family Ornatorotaliidae Benedetti (2015) needs further investigations.

Neorotalia? cretacea sp. nov.
Fig. 11

2010 ? *Sulcoperculina* sp. – Radiočić et al.: pl. 3, figs. 4–6.

Holotype. Specimen 'PUAB 82482', shown in Fig. 11A.
Type locality. Monte delle Castagne, Lepini Mounts, Lazio, Central Italy. See reference in the column (Fig. 2).
Type horizon. Middle-upper part of the Radiolitids Limestone unit, lower Campanian.
Etymology. The specific name is given in allusion of the age of the new species
Number of studied specimens. 37

Description. Medium size, biconvex lamellar perforate shell with chambers arranged in a low trochospire. Both sides of the shell are strongly ornamented. Un-ornamented shell areas are perforated by pores of large calibre. Radial-to-vertical piles occupied the dorsal side, producing clearly visible rounded pustules on shell surface. Funnels developed between piles. The ventral side piles show a particular stellate disposition resembling a rose, due the radial arrangement of the thin funnels. Periphery of the shell is slightly keeled. Funnelled plug is surrounded by a thin spiral canal. The shell is composed of two to two and half whorls with trapezoidal chambers, relatively angular. The last whorl hosts 12–14 chambers. The proloculus is around 30 μm in diameter. Height of the shell varies from 0.52 to 0.58 mm, while the maximum diameter measured reaches 0.98 mm, producing a D/H average of 1.78. Canal system consists of a spiral canal present between two adjacent whorls and interconnected with reticulate canals of the central plug (funnels), and by a spiral (enveloping) and intraseptal interlocular canals.
Associated fauna. *Rotalispira scarsellai*, *R. maxima* sp. nov., *Rotorbinella lepina* sp. nov., *Pilatorotalia pignattii* gen. nov, sp. nov, *Montcharmontia apenninica*, *Dicyclina schlumbergeri*, *Scandonea mediterranea*, *Accordiella conica*, *Keramosphaerina tergestina*, *Murgella lata*. *Praemurgella valenciana*.
Biostratigraphical and Geographical distribution. At present is known from the lower Campanian of Lepini Mounts (Central Italy) and probably from western Serbia.

4. The age of the rotaloidean foraminifera: chronostratigraphy based on SIS

The chronostratigraphic age of the beds containing the rotaloideans studied in this work has been constrained by means of Sr-isotope stratigraphy using both the Sr-data from Schlüter et al. (2008) and Frijia et al. (2015) and the analysis of new samples. The two new studied samples used for SIS come from Central Italy, from a rudist level situated 1 m below the bed with the first occurrence (FO) of *K. tergestina* (Fig. 2) allowing to precisely date the type level of *N.? cretacea*.

The preservation of the analysed fossils was evaluated using an accurate diagenetic screening following the procedure described in detail in previous works (Steuber et al., 2005; Boix et al., 2011; Frijia et al., 2015). Trace element analysis (high Sr content vs. low Mn and Fe concentrations, Table 1) and petrographic observations show no evidence of significant diagenetic alteration of the rudist shells, suggesting that they preserve their pristine chemical composition. Furthermore, internal consistency of the Sr-isotope ratios of the two shell fragments reinforces the hypothesis that they preserve the original Sr-isotope signature of seawater (Table 1).

The ^{87}Sr/^{86}Sr value of 0.707478 ± 11 × 10−6 obtained from the analysed sampled translate into an age of 82.09 (+0.88, −0.89; Table 1) Ma compared with the ^{87}Sr/^{86}Sr reference curve for Cretaceous seawater (McArthur et al., 2001; age derived using the look-up table version 4: 08/04). This age corresponds to the early Campanian, according to the time scale of Gradstein et al. (2004). Moreover, the ^{87}Sr/^{86}Sr average value from the Lepini Mounts section is almost within analytical uncertainty of the values measured by Frijia et al. (2015) from a level 20 m below the FO of *K. tergestina* in the Campanian Apennine Platform (0.707502 ± 9). Finally, the Sr-isotope value from the studied section is almost undistinguishable from that measured by Steuber et al. (2005) from the levels yielding the FO of *K. tergestina* from Brac island (Croatia) (0.707481 ± 9*10−6). We can therefore conclude that the new Sr data from the Lepini Mounts of Central Italy are in agreement with the general early Campanian age of the FO of *K. tergestina* in the periadriatic area.

Unfortunately the beds with the new rotalidean species (*P. pignatti* gen. nov, sp. nov, *R. lepina* sp. nov.) found in the lower part of the studied section cannot be dated as precisely as the level with *N.? cretacea*, due to the lack of suitable material for SIS. These two new taxa occur 45 and 55 m below the *N.? cretacea* type level.

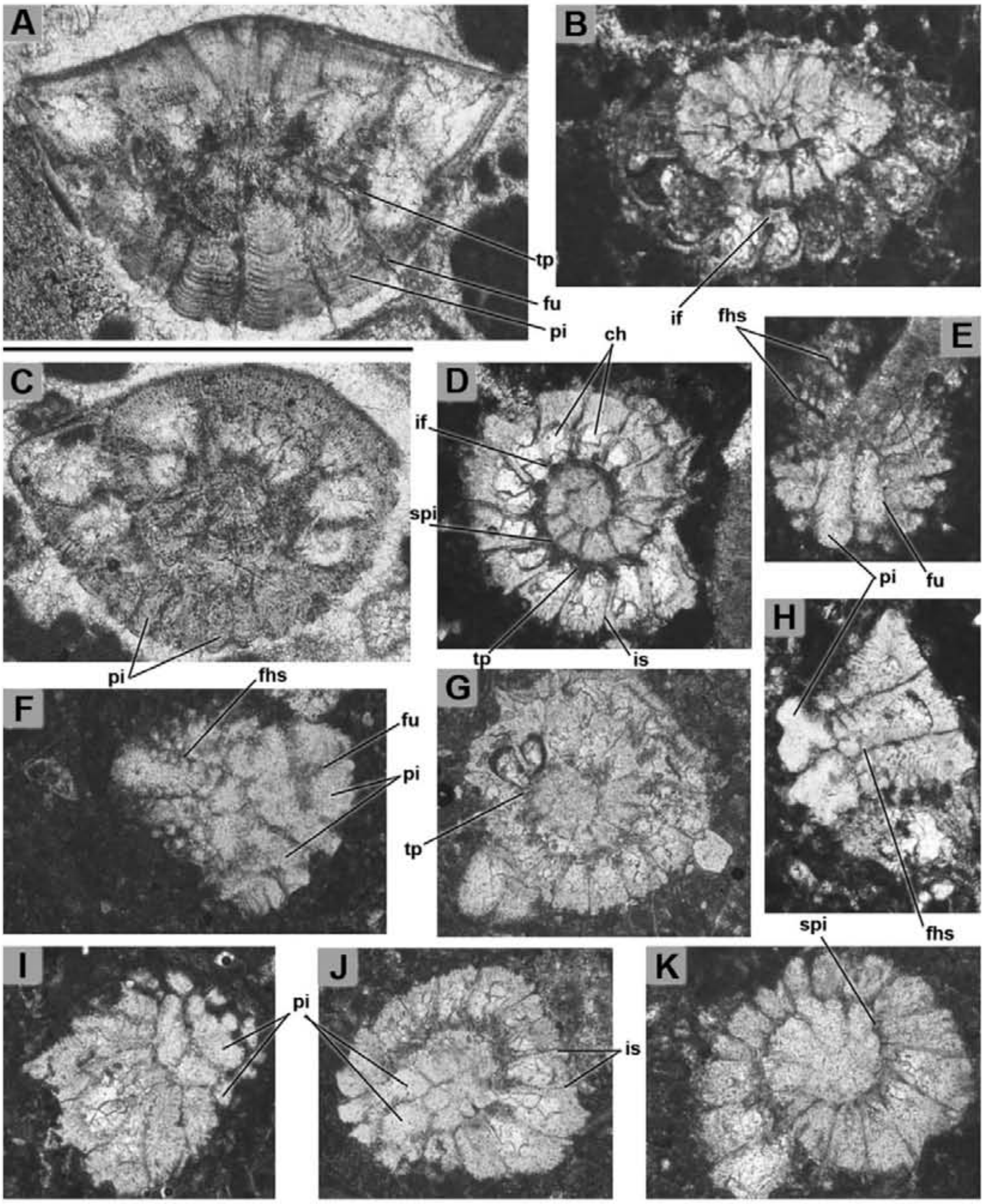

Fig. 10. *Pilatorotalia pignattii* gen. nov., sp. nov. from Lepini Mounts. Scale bar 1 mm for all figures. A. Holotype. Axial section, inner part of the shell appear altered (PUAB 82478 LP02). B. Oblique centred section (PUAB 82483 LP04). C. Oblique section (PUAB 82478 LP01). D. Transversal section showing tooth-plates and the spiral interlocular space filled with fine mud. (PUAB 82483 LP06). E. Transversal section of the umbilical side, note feathered suture (PUAB 82433 LP03). F. Tangential section of feathered sutures and piles (PUAB 82484 LP01). G. Transversal section showing tooth-plate (PUAB 82482 LP02). H. Tangential section cutting feathered sutures (PUAB 82476 LP08). I, J. Tangential sections of the umbilical side (PUAB 82482 LP01 and LP03 respectively). K. Tangential sections of the dorsal side (PUAB 82482 LP06). ch: chamber, fhs: feathered suture, fu: funnel, if: intercameral foramen, is: intraseptal interlocular canal, pi: piles, spi: spiral interlocular space, tp: tooth-plate.

Using the bio-chronostratigraphic scheme developed by Frijia et al. (2015) we suggest an upper Santonian?-lowermost Campanian stage assignment for these two levels.

The published biostratigraphic charts (Velić, 2007; Chiocchini et al., 2012) and chronostratigraphic scheme (Frijia et al., 2015) suggest that *R. scarsellai* is the first rotaloidean foraminifera appearing in the Late Cretaceous GCMC of Central Tethys. It is at least present from the upper Turonian (Frijia et al., 2015), probably in association with some representatives of the genus *Rotorbinella*, with which it has been frequently confused (see Hottinger, 2014 for

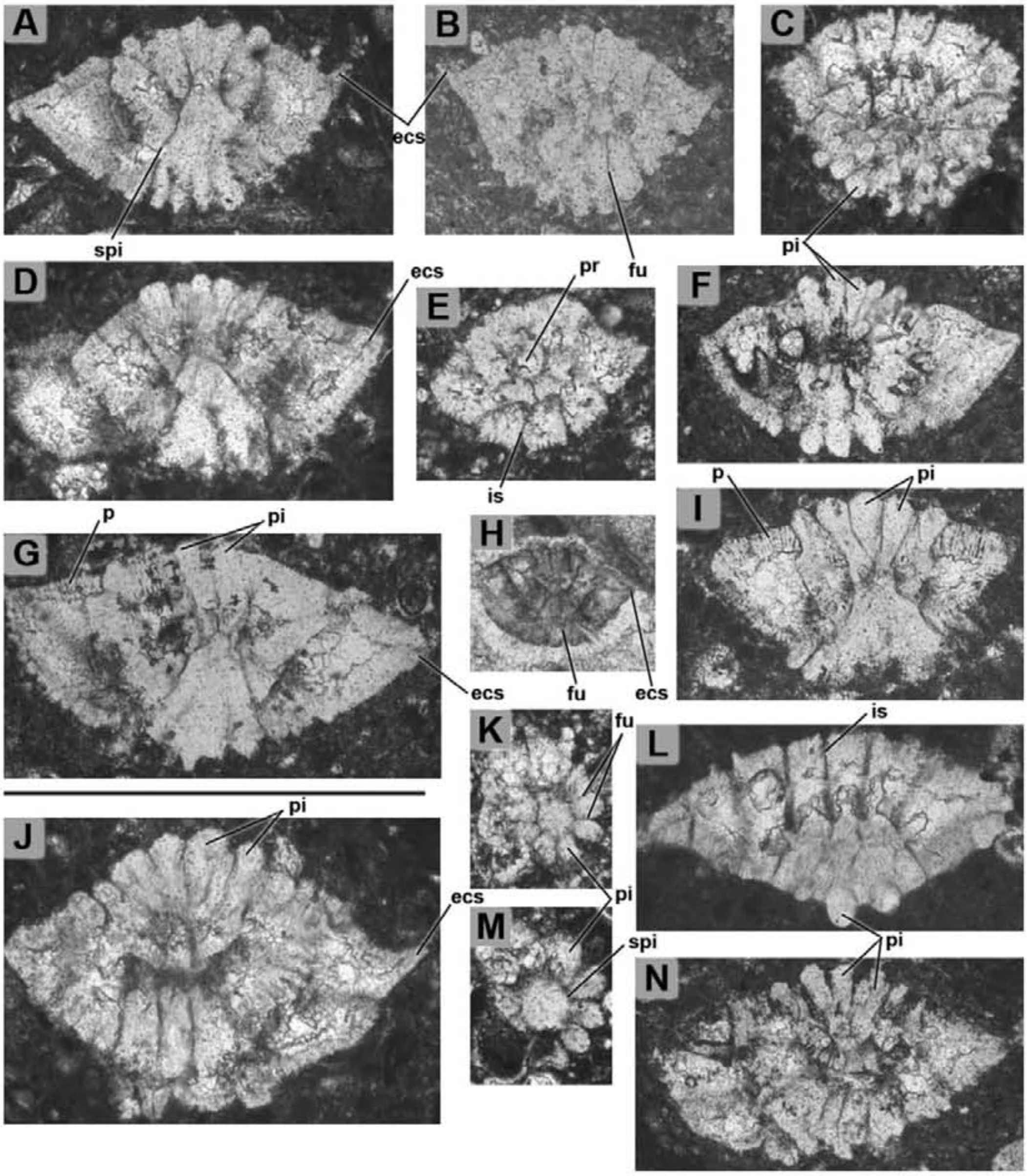

Fig. 11. *Neorotalia*? *cretacea* sp. nov. from Lepini Mounts. Scale bar 1 mm for all figures. A. Holotype. Axial section (PUAB 82482 LP09). B. Close to the axial section (PUAB 82482 LP10). C. Tangential section of the dorsal side showing piles (PUAB 82482 LP01). D. Near to the axial section (PUAB 82482 LP07). E. Tangential section passing through the proloculus (PUAB 82476 LP08). F. Tangential section (PUAB 82482 LP08). G. Axial section, note the enveloping canal occupying the chamber edge (PUAB 82479 LP01). H. Oblique section of a small specimen (PUAB 82478 LP01). I. Close to the axial section (PUAB 82477 LP01). J. Oblique section (PUAB 82482 LP07). K, M. Tangential sections of the umbilical side showing the disposition of umbilical piles and the spiral interlocular space (PUAB 82476 LP06 and LP08 respectively). L. Oblique section (PUAB 82485 LP01). N. Oblique centred section (PUAB 82482 LP12). ecs: enveloping canal system, fu: funnel, if: intercameral foramen, is: intraseptal interlocular canal, p: pore, pi: piles, spi: spiral interlocular space.

comments and the synonym list proposed here). The deposits, today disappeared in the neighbourhood of Pontone (Sorrento peninsula, localities type of *R. scarsellai* and *"Stensioeina" surrentina*) studied by Torre (1966) were probably older than the localities presented in our study, suggesting that the FO of *"Stensioeina" surrentina* take place before the studied rotaloidean ensemble and after the FO of *R. scarsellai*.

5. Rotaloideans in the middle and Late Cretaceous Global Community Maturation Cycle

The data at our disposal (Boix et al., 2009; Piuz and Meister, 2013; Hottinger, 2014, and the papers cited therein) suggest that the origin of the rotaloidean foraminifera took place near the Albian–Cenomanian boundary (middle Cretaceous GCMC)

Table 1
Elemental concentration (ppm), Sr-isotope ratio and SIS ages (Ma) of the studied sample.

Sample	$^{87}Sr/^{86}Sr$ measured	±2 s mean	$^{87}Sr/^{86}Sr$ sample corrected to difference: USGS EN-1 value Mc Arthur and USGS EN-1	±2 se	Ca	Mg	Sr	Fe	Mn	Age min	Age mean	Age max
L–A	0,707464	0,000005	0,707478		391,310	1256	1424	5,5	0,4			
L–B	0,707464	0,000005	0,707478		390,160	1157	1269	6,3	0,2			
		Mean	**0,707478**	0,000011						**81,2**	**82,09**	**82,97**

with two parallel lineages represented at their bases by *Rotorbinella mesogeensis* (Tronchetti) and *Pararotalia boixae* Piuz and Meister. The first one, characterised by the presence of folium and umbilical plate, is considered the progenitor of all rotaliids (Rotaliidae family) as already stated by Boix et al. (2009), while the last one exhibiting a tooth-plate closing the spiral chamber probably represents the root of the pararotaliids (Pararotaliidae family). Their small sizes, relatively simple umbilical architecture, and the lack of adult dimorphism suggest an r-strategy of life for these rotaloideans (Hottinger, 2014), which probably helped them to escape extinction at the Cenomanian–Turonian boundary Event (CTB). Moreover, Cenomanian rotaloideans are widely distributed. In addition to the Pyrenean realm, they are known in the Tethyan realm from the Iberian Peninsula to Oman and Iran. In America, *R. mesogeensis* is present in the Cenomanian deposits of Peru (unpublished data), and rotaliids with strong affinities to *R. mesogeensis* have been demonstrated by Rosales-Dominguez et al. (1997, fig. 4E) from the Cenomanian of Chiapas (Mexico).

After the Cenomanian/Turonian mass extinction (Late Cretaceous GCMC) Rotaliidae and Pararotaliidae diversified independently, at least into three separated palaeobioprovinces: Tethyan, Pyrenean and Caribbean (Caus et al., 2007). However, at present the regional data are insufficient to evaluate if this diversification was contemporaneous or not. In the Pyrenean palaeobioprovince, the diversification started during the late Turonian-early Coniacian with *Rotorbinella campaniola*, and reached maximum diversity near the Coniacian–Santonian boundary with the appearance of very large morphotypes (*Pyrenerotalia* Boix et al., *Iberorotalia* Boix et al., and *Orbitokathina* Hottinger) interpreted as k-strategists (Boix et al., 2011). In the Tethyan palaeobioprovince, *R. scarsellai* appeared in the late Turonian (Frijia et al., 2015), while large morphotypes such as *R. maxima* sp. nov. appear only in the early Campanian. Finally, rotaloideans seem to lose importance in both Pyrenean and Tethyan palaeobioprovinces during late Campanian and Maastrichtian stages, when only non-described small forms and the genus *Laffiteina* existed. In the Caribbean palaeobioprovince "*Kathina*" *jamaicensis* Cushmann and Jarvis, and "*Lockhartia*" *susuaensis* Pesagno associated with non-described morphotypes seem to characterise the latest Cretaceous near the K/Pg boundary (Brown and Brönnimann, 1957; Boix et al., 2009).

6. Conclusions

The study of the Upper Cretaceous shallow-water carbonates of Central and Southern Italy has led to the description of five new rotaloidean foraminifera, which are included in the family Rotaliidae (*Rotorbinella lepina*, *Rotalispira vitigliana* and *R. maxima)* and in the family Pararotaliidae (*Pilatorotalia pignattii* and *Neorotalia? cretacea*). Moreover, the two rotaloidean taxa, *Rotalispira scarsellai* and "*Stensioeina*" *surrentina*, previously described (Torre, 1966) have been identified, and their architecture has been discussed. Strontium Isotope stratigraphy allowed to precisely date the new described taxa to the late Santonian?-middle Campanian. Therefore, these foraminifera could permit the lower Campanian shallow-water deposits of the perimediterranean area to be biostratigraphically characterised when other taxa are missing.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cretres.2016.11.004.

5.4 Article 5

Author’s contribution

New rotaliids (benthic foraminifera) from the Late Cretaceous of the Pyrenees.

Journal: The Journal of Foraminiferal Research
State: under review
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NEW ROTALIIDS (BENTHIC FORAMINIFERA) FROM THE LATE CRETACEOUS OF THE PYRENEES, NE OF SPAIN

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ABSTRACT

The shallow-water carbonate deposits of the southern Pyrenees host a rich fauna of larger benthic foraminifera largely studied since the latter part of the 19th century. In this paper, two new rotaliids, *Rotalispirella acuta* n. gen., n. sp., and *Suturina globosa* n. gen n. sp., have been described from the interval Campanian-lowermost Maastrichtian and their suprageneric assignment is proposed. The age of the new rotaliids is constrained by means of strontium isotope stratigraphy. The presence of *Suturina* n. gen. in the Late Maastrichtian of Iran (Tarbur Fm.) reveals a wider distribution of this taxon which presence is not restricted to the Pyrenean palaeobioprovince.

Key words: Rotaliid Foraminifera, Architecture, Campanian-lowermost Maastrichtian, Pyrenees

INTRODUCTION

The Late Cretaceous Pyrenean basin was a NW-SE narrow and deep gulf imbedded between Iberia and Europe. It was opened to the Atlantic Ocean but isolated from the Tethyan Sea since Coniacian. Besides, shallow-water carbonate and siliciclastic-carbonate shelves extensively developed along the margins. These deposits were subsequently folded, fragmented and detached from their substrates during the Alpine (Pyrenean) Orogeny (latest Cretaceous-Miocene, Roest & Srivastava, 1991; Rosenbaum et al, 2002). As a result, today outcrops are disposed into several tectonic units distributed from the North of Spain (from the Cantabrian Mountains to the eastern Pyrenees) to the South of France (Aquitaine to Provence).

The larger benthic foraminifera contained in these sediments appears often very well conserved and have attracted the attention of geoscientists since the latter part of the 19th century. In this context many groups were thoroughly investigated (Schlumberger, 1899; Wannier, 1980; 1983; Drooger & Klerck, 1985; Neumann, 1986; 1997; Hottinger et al., 1989; Hottinger & Caus, 2007, 2009; Albrich et al., 2016; among others); however, the inventory is not finished. Such is the case of the rotaloidean foraminifera which abundance, diversity, high evolutionary rate and biostratigraphic value have recently been detailed in the Palaeocene (see Hottinger, 2014). In the Late Cretaceous of the Pyrenean domain, the rotaloideans were studied by Hottinger (1966) in the Southern Pyrenees, followed by Tronchetti (1981) in Provence, and more recently by Boix et al. (2009). Despite this, several morphotypes still remain unlisted.

Thus, the aim of this paper is to introduce two new rotaloidean foraminifera from the Campanian and lower Maastrichtian deposits of the Southern Pyrenees. These new reports pretend to enrich the extensive list of larger benthic foraminifera of the Pyrenean palaeobioprovince (Hottinger et al., 1989; Hottinger & Caus, 2007; 2009; Boix et al., 2009; Consorti et al., 2016 among others), which represents a Late Cretaceous hotspot of diversity and endemisms over the Coniacian-Campanian interval (Caus & Hottinger, 1986; Caus et al., 2007; Goldbeck & Langer, 2009). The new genus *Suturina* has also been found in the Late Maastrichtian of Tarbur Formation (Iran) together with a rich assemblage of larger benthic foraminifera (Schlagintweit et al., 2016; Schlagintweit & Koorosh, 2016). Finally, this new occurrence sheds light on the dispersal patterns between Pyrenean gulf and Tethyan Ocean during the terminal stage of the Late Cretaceous Global Community Maturation Cycle (GCMC) sensu Hottinger (2001).

GEOLOGICAL SETTING AND STRATIGRAPHY

The new rotaloidean foraminifera are from the Marginal Mountains in northeastern Spain (Serres Marginals thrust sheet of the South Central Pyrenean unit, Seguret, 1972; Muñoz et al., 1986; Fig. 1A), although they are also present in isochronous deposits of other tectonic units such as in the Montsec Mountains.

The Marginal Mountains form a set of hills, whose general direction is E-W, traversed by the Noguera-Ribagorçana and the Noguera-Pallaresa rivers forming abrupt gorges where reservoirs were built in the lows (Fig. 1B). The stratigraphy of the Marginal Mountains consists of thick successions of mainly Late Cretaceous age deposits, which lie S to N, successively, on Triassic and Jurassic age sediments. In some sections bauxites levels mark the contact with the underlying deposits. The Upper Cretaceous deposits gradually reduce their thickness, from about 400m thick to the N to less than 100m to the S. They are divided, from bottom to top, in two lithostratigraphical units: Serres Marginals sandy unit and Serres Marginals limestone unit (Souquet, 1967) (Fig. 2).

SERRES MARGINALS SANDY UNIT

In the northerly outcrops (for instance: Coscoll section, Fig. 3), the Serres Marginals sandy unit consists of marly limestones, marls and sandy limestones with packstone-wackestone textures. These deposits host rudists, ostreids, echinoids, larger benthic foraminifera and rare corals. To the S (for instance: Montroig section, Fig. 4), siliciclastics increasingly dominate consisting of sandstones, microconglomerates and clays with interbedded marly-sandy limestones less than 3m thick. Sandstones are fine to coarse grained, medium scale cross-bedding with limonitic crust. Here, larger benthic foraminifera-bearing deposits are uncommon due to the significant terrigenous component (Villalonga, 2009). Total thickness varies from 30 m to 50 m.

In the Serres Marginals sandy unit two successive larger benthic foraminiferal assemblages have been identified: the lower one corresponds to the 'Tragó de Noguera assemblage' (Schlumberger, 1899). This association, N of the studied area (Montsec Mountains), has been dated as early Campanian. The upper assemblage contains *Cyclopsinella* sp., *Accordiella conica* Farinacci, *Ilerdorbis decussatus* Hottinger & Caus, *Calveziconus lecalvezae* Caus & Cornella, *Fascispira schlumbergeri* Hottinger & Caus, *Rotorbinella campaniola* Boix et al., *Orbitokhatina campaniana* Boix et al. and *Suturina globosa* n. gen., n. sp. This assemblage was dated in the Montsec Mountains (20 km northward of the studied area) by means of Sr- isotope stratigraphy as middle Campanian age (G. Frijia & M. Parente personal communication).

SERRES MARGINALS LIMESTONE UNIT

The Serres Marginals limestone unit forms an impressive cliff above the underlying Serres Marginals sandy unit, and can be subdivided into three subunits, clearly observable in the landscape from bottom to top (Figs 2-4):

a) Subunit A consists of grey well-stratified peloidal packstones with fine to medium-grained constituents, including larger benthic foraminifera. Rudists and other bivalves are also present, but frequently fragmented. In the upper part of the subunit, mainly in the southernmost sections, the deposits are partly dolomitised. These facies are interpreted as deposited in a shallow-water setting, whose fossil content indicates a infralittoral to mesolittoral environment (Villalonga, 2009). The thickness of this subunit varies from 10 m to 35 m. Larger benthic foraminiferal content is uniform throughout the whole subunit. We can highlight the presence of *I. decussatus*, *C. lecalvezae* and *O. campaniana*, together with *Abrardia catalaunica* Bilotte, *Accordiella conica*, *Dicyclina schlumbergeri* Munier-Chalmas, *Cyclopsinella* sp., *Rotalispirella acuta* n. gen., n. sp. and *Suturina globosa* n. gen., n. sp. The presence of Siderolitidae and Orbitoididae is rare; only small *Praesiderolites* cf. *douvillei* were observed.

b) Subunit B can easily be distinguished from the underlying subunit A by a rapid colour change, from grey to ochre. It is constituted by massive limestones with grainstone and less frequently packstone textures with abundant bryozoans, algae, echinoid, bivalves and larger foraminifera. Among the latter ones, *Siderolites praecalcitrapoides* Neumann and, locally, *Lepidorbitoides* have been found together with *Rotalispirella acuta* n. gen., n. sp. The thickness of this subunit varies from 20 m to 120 m. We must note that only a small part of subunit B has been sampled in the Coscoll section due to the inaccessibility of the terrain (see Fig. 3). The presence of *S. praecalcitrapoides* suggests a late Campanian age for this subunit (Robles-Salcedo et al., 2013;

Caus et al., 2016).

c) Subunit C base in the Coscoll section is constituted by a maximum thickness of 10m of nodular limestone hosting abundant colonial coral and radiolitids (easily identified in the field as a terrace between the two limestone intervals, Fig. 3) which grades upwards to massive to thickly-bedded bioclastic limestone with abundant larger benthic foraminifera. In the south, (e.g. Montroig section), this subunit lack of the nodular limestone interval and is separated from subunit B by a karstified emergent surface (Villalonga, 2009). In both sections, from bottom to top, two larger foraminiferal assemblages have been identified: 1) *S. praecalcitrapoides*, *Orbitoides* aff. *concavatus*, *Rotalispirella acuta* n. gen., n. sp. and 2) *S.* aff. *calcitrapoides* (small-sized specimens compared to *S. calcitrapoides*, see discussion in Robles-Salcedo et al., 2013), *Omphalocyclus macroporus* Lamarck, *Orbitoides* sp., *Rotalispirella acuta* n. gen., n. sp., *Fallotia jacquoti* Douvillé and *Fascispira colomi* Silvestri. Using Sr isotope data and according to the foraminiferal association, Caus et al., (2016) suggested a late Campanian age for the former assemblage, while the latter one is earliest Maastrichtian in age. The Serres Marginals unit ends with a rudist level (*H. radiosus* level) which can be followed in all of the Marginal Mountains and far north in the Montsec and Boixols thrust sheet (Vicens et al., 2004). The thickness of subunit C varies from 150 m to 40 m. Upwards, decimetric-thick grey micritic limestones with charophyte remains, ostracods and fresh-water molluscs indicate the end of the marine sedimentation in this area of the South-Pyrenean basin (Grey Garumnian facies in Rosell et al., 2001).

MATERIAL AND METHODS

The description of the new taxa is entirely based on thin sections. We studied 143 sections from 103 hard rock samples from Coscoll and Montroig stratigraphic sections (sample position is indicated in Fig. 2). 45 supplementary thin sections come from equivalent stratigraphic levels in Sant Jordi (Marginal Mountains); Pas de Montebrei and Cabana del Gabrieló (Montsec Mountains) (see for details Villalonga, 2009). More than 160 random rotaliid sections have been used for systematic studies. The works of Billmann et al. (1980), Boix et al. (2009) and Hottinger (2014) are followed for structure identification and characterization of the architectural elements in rotaliids. The terminology used is from Hottinger (2006). Figured and supplementary material has been deposited in the collection of Micropalaeontology of the Universitat Autònoma de Barcelona (Spain) under the PUAB numbers 82488-82512.

Three supplementary *Suturina* n. gen. sections from Iran have also been studied and incorporated to this work (Fig. 7). They come from Tarbur Fm in SW Zagros basin (Mandegan area), from a level indicated as Unit 1 in Schagintweit & Koorosh (2016, see their fig. 4). In this locality, the knowledge of the larger benthic foraminifera and algae has been recently improved by Schlagintweit et al. (2016) and Schagintweit & Koorosh (2016), where a rich foraminiferal assemblage comprising new taxa as *Accordiella*? *tarburensis*, *Spiroina*? *farsiana* and *Loftusia* Brady, *Neobalkhania* Cherchi, Radiočić & Schroeder, *Laffitteina* Marie, *Gyrocornulina* Schroeder & Darmoian and *Omphalocyclus* indicates Late Maastrichtian age

SYSTEMATIC MICROPALAEONTOLOGY

Phylum FORAMINIFERA (d'Orbigny 1826) Pawlowski et al., 2013
Class GLOBOTHALAMEA Pawlowski et al., 2013
Order ROTALIIDA Delage & Hérouard, 1896
Superfamily ROTALOIDEA Ehrenberg, 1839, revised Hottinger, 2014

Remarks: for superfamily discussion see Hottinger (2014) and Consorti et al. (2017).

Family ROTALIIDAE Ehrenberg, 1839, revised Hottinger 2014

Remarks: see Consorti et al. (2017).

Subfamily LOCKHARTIINAE Hottinger, 2014

Remarks: According Hottinger (2014), the subfamily Lockhartiinae is characterised by low trochospiral shells with long and oblique folia supported by piles covering large parts of the umbilicus. These characteristics have been observed in *Rotalispirella* n. gen.

Genus *Rotalispirella* nov.
Type-species *Rotalispirella acuta* n sp.

Derivation nominis: The generic name is given due to the apparent analogy with the Tethyan genus *Rotalispira* (Torre).

Diagnosis: Small-sized, very low trochospiral perforated shell. The dorsal side is flat and sutures between whorls are limbate. Ventral side is flat to convex and largely occupied by oblique folia and thin foliar piles. Consecutive folia are superposed like the blade of a propeller while foliar piles appear sometimes adaxially fused. The first whorl is composed of double-keeled chambers arranged in a low trochospire; these chambers possess a rectangular or slightly trapezoidal outline in transverse section. Successive whorls are built by trapezoidal chambers in transverse cuts, appearing trapezoidal to-triangular slightly rounded in axial section with an acute and keeled periphery; keels reduce gradually from two to one during ontogeny. Umbilical plate separates the chamber lumen from the foliar chamberlet. The canal system is formed by the spiral interlocular space and is constrained by subsequent folia. Intraseptal interlocular spaces are also present.

Remarks: Hottinger (2014) considered *Rotalispira* as the genus from which *Lockhartia* may have arisen. However, the foliar piles in *Rotalispira* are always maintained separated from each other. In contrast, in *Rotalispirella* nov. gen. the foliar piles may fuse adaxially, more probably during some casual phases of reabsorption involved in the construction of the shell. The adaxial fusion of foliar piles which starts in the Late Cretaceous with *Rotalispirella*, may at the moment be considered the first real transition between foliar piles and true piles developed in Tertiary Lockhartines.

Differential diagnosis: *Rotalispirella* nov. gen. differs from *Rotalispira* in having a double-keeled periphery in the first growth steps, adaxially fused foliar piles and angular chamber outline. *Rotalispirella* differs from *Rotospirella* Hottinger because its trochospire is very low and its dorsal side is ornamented by limbate sutures. *Lockarthia* develops true, thick and densely packed umbilical piles, while *Rotalispirella* develop only few, sparse and thin umbilical piles. The Pyrenean genera *Pyrenerotalia* Boix et al. and *Iberorotalia* (Hottinger) possess smooth dorsal sides and chambers are arranged in a more or less high trochospire unlike *Rotalispirella*. Furthermore in the latter ones, folia are not superposed.

Rotalispirella acuta n. sp.
(Fig. 5)

2009 new genus? - Villalonga, Pl. 23, Figs.1-3, 6, 8, 10, 11.

Holotype: Specimen figured in Fig. 5.1, repository number: PUAB 82488 LP01.01

Type locality: Montroig section, Serres Marginals (Lleida, N Spain). Base of the section: N 41º53’40” - E 0º50’05”.

Type horizon: Serres Marginals limestone unit, subunit 1.

Etymology: The specific name is given because the acute shape of the keeled periphery.

Diagnosis: Small-sized (nearly 1 mm in diameter), very low trochospiral perforated shell with flat, ornamented dorsal side. Lamellar thickening due to the formation of successive lamellae during ontogeny is evident especially in the first growth step. The periphery of the shell is angular and keeled, double-keeled in the first 1.5 whorls and subsequently single-keeled. When single-keeled, its position may fluctuate from central to ventral. Ventral side flat or slightly convex and largely occupied by folia and foliar piles. Folia are very long superposed like the blades of a propeller. Foliar piles arise adaxially at the inner end of each folium. The shell is composed of 2-2.5 whorls; the double-keeled chambers are slightly rectangular while the others are trapezoidal in edge view. There are at least 7-8 chambers in the first whorl and approximately 10-12 in the second. Proloculus diameter varies from 53µm to 80µm. Septa are thick, approximately 20µm for those of the first whorl and 30µm for those of the second. Shell diameter varies from 0.6 mm to 0.95 mm, while the height is approximately around 0.27-0.3 mm; the average D/H ratio is around 2.6. Intraseptal interlocular spaces are present along the septa. Spiral interlocular space is thin.

Associated fauna: *I. decussatus*, *C. lecalvezae*, *O. campaniana*, *A. catalaunica*, *D. schlumbergeri*, *Cyclopsinella* sp., *S. praecalcitrapoides*, *P.* cf. *douvillei*., *O. macroporus*, *Suturina globosa* n. gen., n. sp., *F. jacquoti* and *F. colomi*.

Biostratigraphical and Geographical distribution: At present it is only known from the Campanian and lowermost Maastrichtian of the Pyrenees.

? Subfamily ROTALIINAE Ehrenberg 1839

Remarks: This subfamily has been defined as characterised by the absence of dorsal ornamentation and the ventral spaces subdivided by free-standing piles. The foliar suture is marked by a notch.

At the moment we prefer to keep *Suturina* n. gen. in the Rotaliinae subfamily. But, unlike the representatives of Rotaliinae (in Hottinger, 2014), *Suturina* n. gen. lack of columellar fillings such as foliar piles, piles or fused folia.

Genus *Suturina* nov.
Type-species *Suturina globosa* n sp.

Derivation nominis: The generic name is given due to the presence of incised chamber sutures in the ventral side.

Diagnosis: Hemispherical medium-sized, coarsely perforated, trochospiral shell. Dorsal side flat with slightly marked dorsal chamber sutures. Ventral side flat or slightly concave with incised chamber sutures. Umbilicus deep and filled by thin, short and very oblique superposed, but not fused, folia. There is a thin umbilical plate separating the chamber lumen from the foliar chamberlet. Intercameral foramina are wide. Intraseptal interlocular spaces are present within septa, spiral interlocular space reduced occupying the umbilicus and constrained by folia.

Differential diagnosis: The presence of incised suture placed between chambers and smooth periphery are features only found in *Suturina* and never seen within the Cretaceous rotaliid Pyrenean genera *Iberorotalia*, *Pyrenerotalia* or *Orbitokathina*.

The hemispherical Palaeogene genera *Cincoriola* Haque and *Rahaghia* Hottinger have no folia or umbilical plate, unlike *Suturina*.

Suturina globosa n. sp.
(Fig. 6)

Holotype: Specimen figured in Fig. 6.1, repository number: PUAB 82504 LP01.01

Type locality: Coscoll section, Serres Marginals (Lleida, N Spain). Base of the section: N 41º53’40” - E 0º51’20”.

Type horizon: Serres Marginals sandy unit.

Etymology: The specific name is given because the rounded outline of the shell.

Diagnosis: Medium-sized, coarsely perforated, trochospiral shell with the basic architecture of Suturina. Lamellar thickening due to the formation of successive lamellae during ontogeny is evident especially in the first chambers. The periphery of the shell is rounded to elliptic and lacks keel. Ventral side occupied by folia which are short and superposed in successive chambers. Shell is composed of almost 3-3.5 whorls. Chambers are rounded and increase suddenly in size during growth after the second whorl; the final chambers may be up to ten times bigger with respect to the first. There are approximately 3-4 chambers in the first whorl and 6-7 in the second. Proloculus diameter is around 40µm. Septa thickness is approximately 40µm for those belonging to the first whorls with thick wall and 25µm for those belonging to the successive whorl. Shell diameter varies from 0.8 mm to 1.2 mm, while the height is approximately 0.5-0.7 mm; the average D/H ratio is around 1.6. Sutures between chambers swallow almost one third of the septa, the successive chamber margins widen to about 45µm. Intraseptal interlocular spaces are present along the septa. Spiral interlocular space thin and constrained in the ventral side.

Remarks: The assignment of the specimens from Tarbur Fm (Fig. 7) to the *S. globosa* remains doubtful due to the lack of centered and good trasverse sections. Although, the abrupt change in chamber dimension during growth (see Fig. 7.1) suggests close relations with *S. globosa* n. gen. n. sp., we prefer to keep *Suturina* cf. *globosa* until further studies.

Associated fauna: *I. decussatus*, *C. lecalvezae*, *O. campaniana*, *A. catalaunica*, *A. conica*, *D. schlumbergeri*, *Cyclopsinella* sp., *Rotalispirella acuta* n. gen., n. sp., *P.* cf. *douvillei*.

Biostratigraphical and Geographical distribution: At present it is only known from the Campanian of Pyrenees, and probably from the Late Maastrichtian of Iran.

CONCLUSION

Two new rotaliid foraminifera from the Late Cretaceous of the Pyrenees have been described. *Rotalispirella acuta* n. gen, n. sp. is characterised by a low trochospire with flat dorsal side and flat to convex ventral side. The shell has an acute and keeled periphery. The ventral side is largely occupied by oblique folia and foliar piles, which are commonly adaxially fused. *Suturina globosa* n. gen., n. sp. is a hemispherical, coarsely perforated, trochospiral shell. Dorsal side flat or slightly convex and ventral side mostly flat with incised chamber sutures. Umbilicus filled by thin, short and very oblique superposed, but not fused, folia. Thin umbilical plate.

The discovery of the hemispherical rotaliid *Suturina* n. gen. in Iran suggests a certain degree of faunal permeability between the Pyrenean and the Tethyan palaeobioprovinces during Campanian-Maastrichtian times. Contrarily, *Rotalispirella* n. gen seems to be restricted to the Pyrenean gulf, while its closely allied *Rotalispira* has only been reported from central Tethys.

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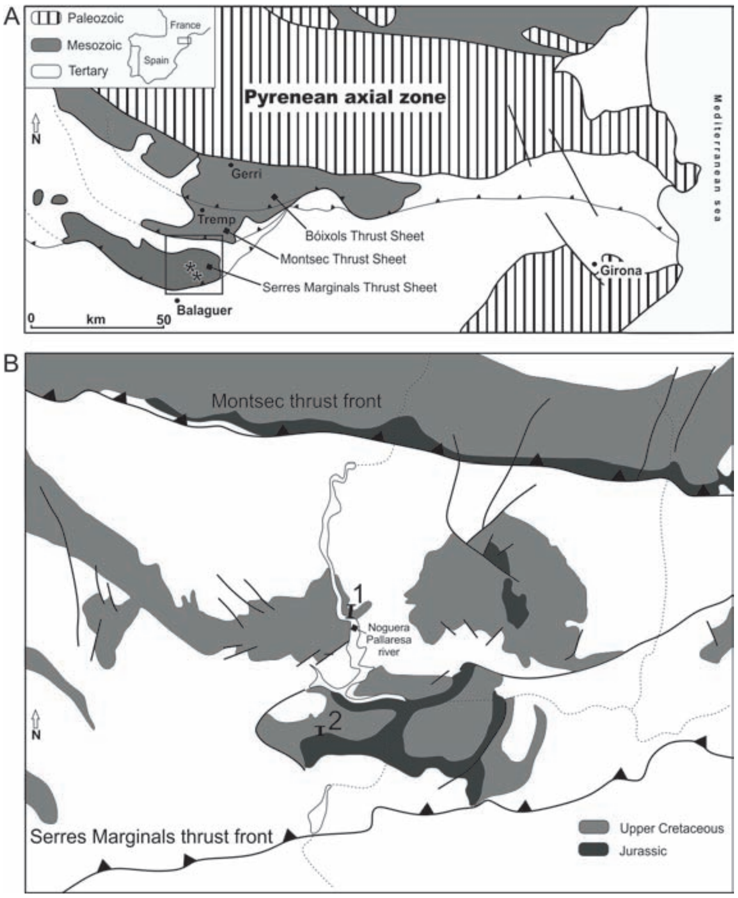

FIGURE 1. A: South-central Pyrenean unit with the Bóixols, Montsec and Serres Marginals thrust sheets. The square indicates the area of study and asterisks indicate the position of the figured columns. B: Area of study. Jurassic and Cretaceous outcrops in the Marginal Mountains (Serres Marginals thrust sheet). 1: Coscoll section; 2: Montroig section.

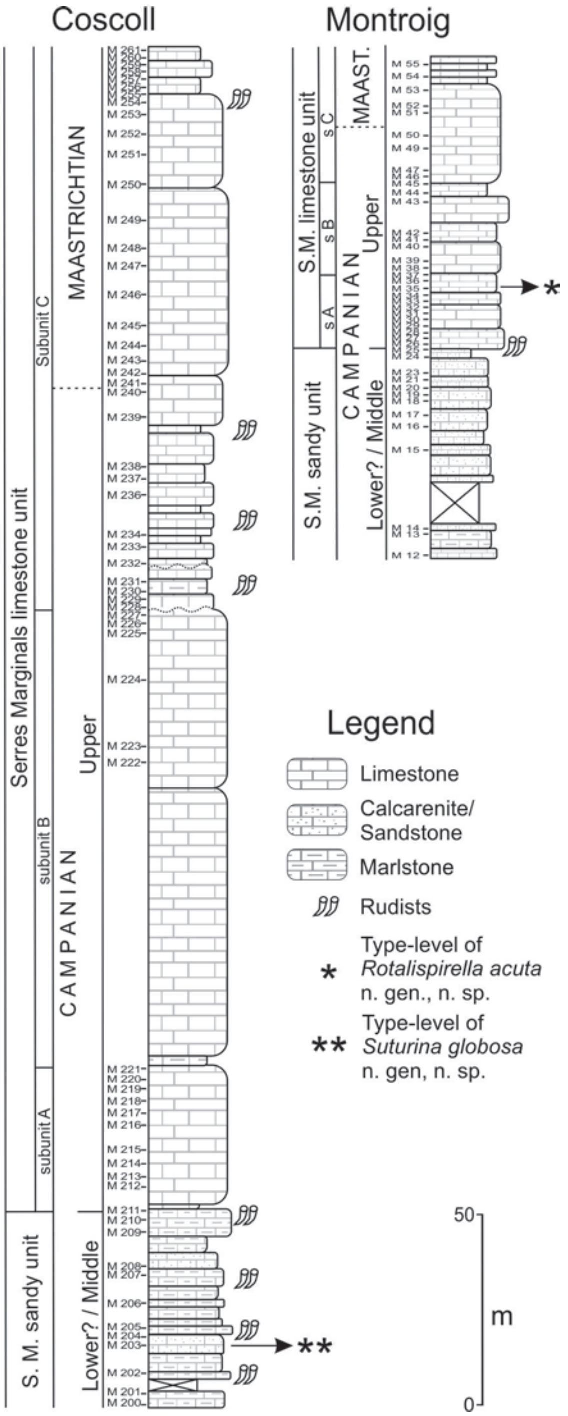

FIGURE 2. Coscoll and Montroig stratigraphic sections. Note the position of the studied samples, and the position of the type levels of *S. globosa* and *R. acuta.*

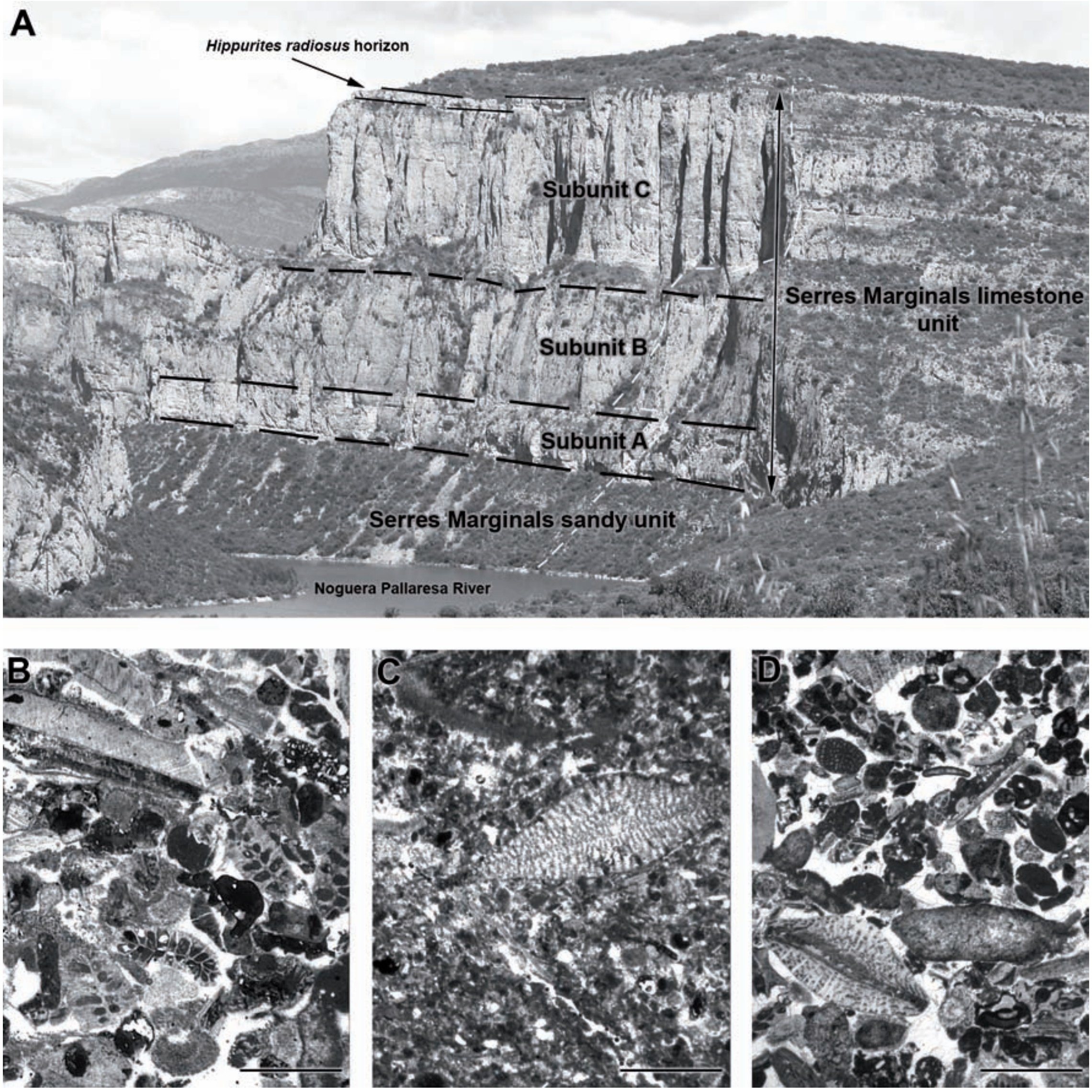

FIGURE 3. A: Coscoll Mountain image with the stratigraphic units and subunits described in the text. White dotted line indicates the measured section. B: Grainstone with bryozoans, bivalves and agglutinated foraminifera. From the subunit A (sample M-221). C: Wackestone-packstone with *Lepidorbitoides* from the subunit B (sample M-228). D: Grainstone with *Orbitoides* and Siderotidae from the subunit C (sample M-246). Scale bar 1 mm.

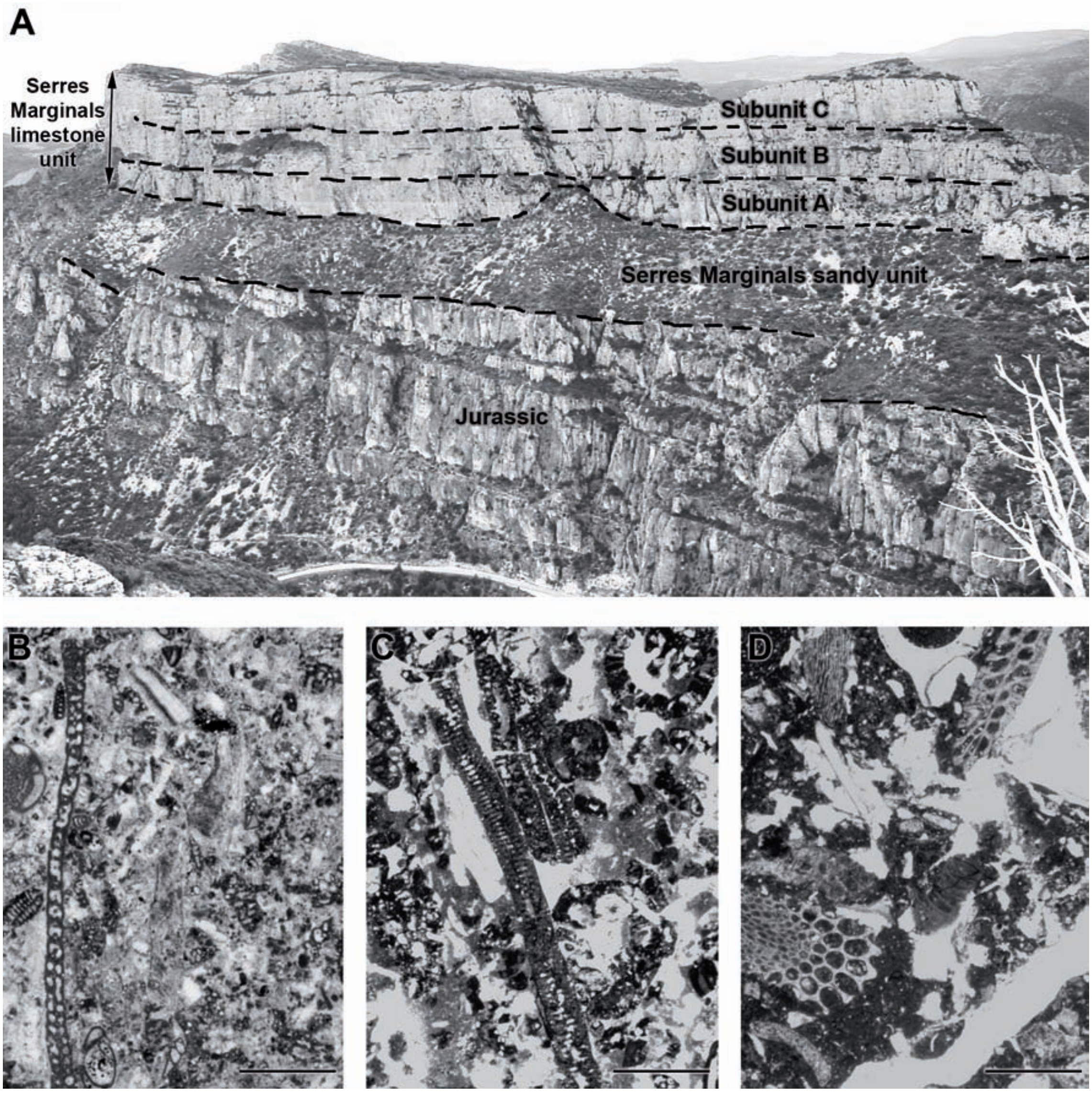

FIGURE 4. A: Montroig Mountain image with the stratigraphic units and subunits described in the text. B: Bioclastic packstone with *Accordiella conica*, *Cyclopsinella* sp., miliolids and few quartz grains. From the Serres Marginals sandy unit (sample M-18). C: Packstone-grainstone with *Dicyclina* and *Lituola* sp. From the subunit A (sample M-33). D: Packstone with bryozoans. From the subunit B (sample M-40). Scale bar 1 mm.

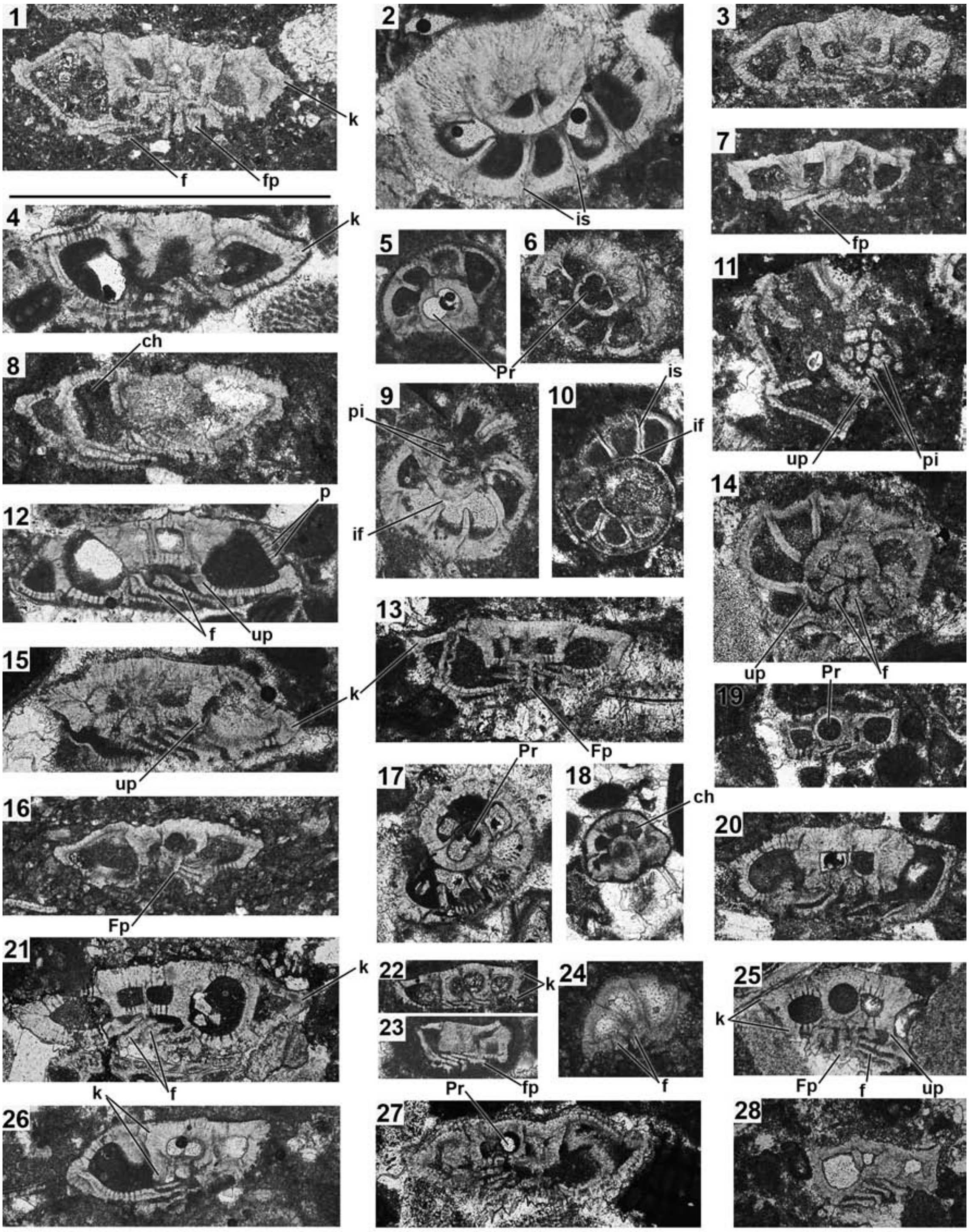

FIGURE 5. *Rotalispirella acuta* n. gen, n. sp. Scale bar 1 mm for all the specimens. 1, 3, 6-8, 10, 11, 13, 14, 16, 19, 24, 28 from Montroig section (Marginal Mountains); 2, 4, 5, 9, 12, 20, 21, 25, 26 from Coscoll section (Marginal Mountains); 22 form Sant Jordi (Marginal Mountains). 15, 17, 27 from Pas de Montebrei (Montsec Mountains); 23 from Cabana del Gabrieló (Montsec Mountains). For samples of the Sant Jordi, Pas de Montrebei and Cabana de Gabrieló see the field and stratigraphic position in Villalonga (2009). 1 Holotype. Axial section (PUAB 82488 LP01.01). 2 Oblique section with septa and intraseptal canals (PUAB 82489 LP01.01). 3 Close to the axial section (82488 LP01.02). 4 Tangential section; note the acute and keeled periphery (PUAB 82489 LP02.01). 5, 6 Transversal sections with the embryonic chambers (PUAB 82490 LP01.01 and PUAB82491 LP01.01, respectively). 7, 8 Subaxial sections (PUAB 82488

LP01.03 and LP01.04 respectively). 9, 11 Transversal sections cutting the umbilicus; note the umbilical piles (PUAB 82490 LP01.02 and PUAB 82488 LP01.05 respectively). 10 Transversal section showing the dorsal side of the shell (PUAB 82492 LP01.01). 12, 15 Subaxial sections; note the superposed folia occupying the umbilicus (PUAB 82489 LP03.01). 13 Close to the axial section; see piles adaxially fused (PUAB 82493 LP01.01). 14 Transversal slightly oblique section (PUAB 82493 LP01.02). 16 Axial section (PUAB 82495 LP01.01). 17, 19 Transversal sections showing the embryo (PUAB 82496 LP01.01). 19 Axial section of a juvenile specimen (PUAB 82498 LP01.01). 20, 21 Subaxial sections (PUAB 82490 LP02.01 and PUAB 82499 LP LP01.01). 22 Axial section (PUAB 82500 LP01.01). 23 Tangential section, note folia and foliar piles (PUAB 82501 LP01.01). 24 Chambers and folia cut tangentially (PUAB 82495 LP01.02). 25 Axial section, note adaxially fused piles (PUAB 82499 LP01.02). 26, 28 Subaxial sections (PUAB 82490 LP01.03 and PUAB 82503 LP01.01). 27 Axial section (PUAB 82503 LP01.01). Pr: proloculus; pi: pile; f: folium; k: keel; if: intercameral foramen; up: umbilical plate; is: intraseptal canal; fp: foliar pile; Fp: fused piles; ch: chamber.

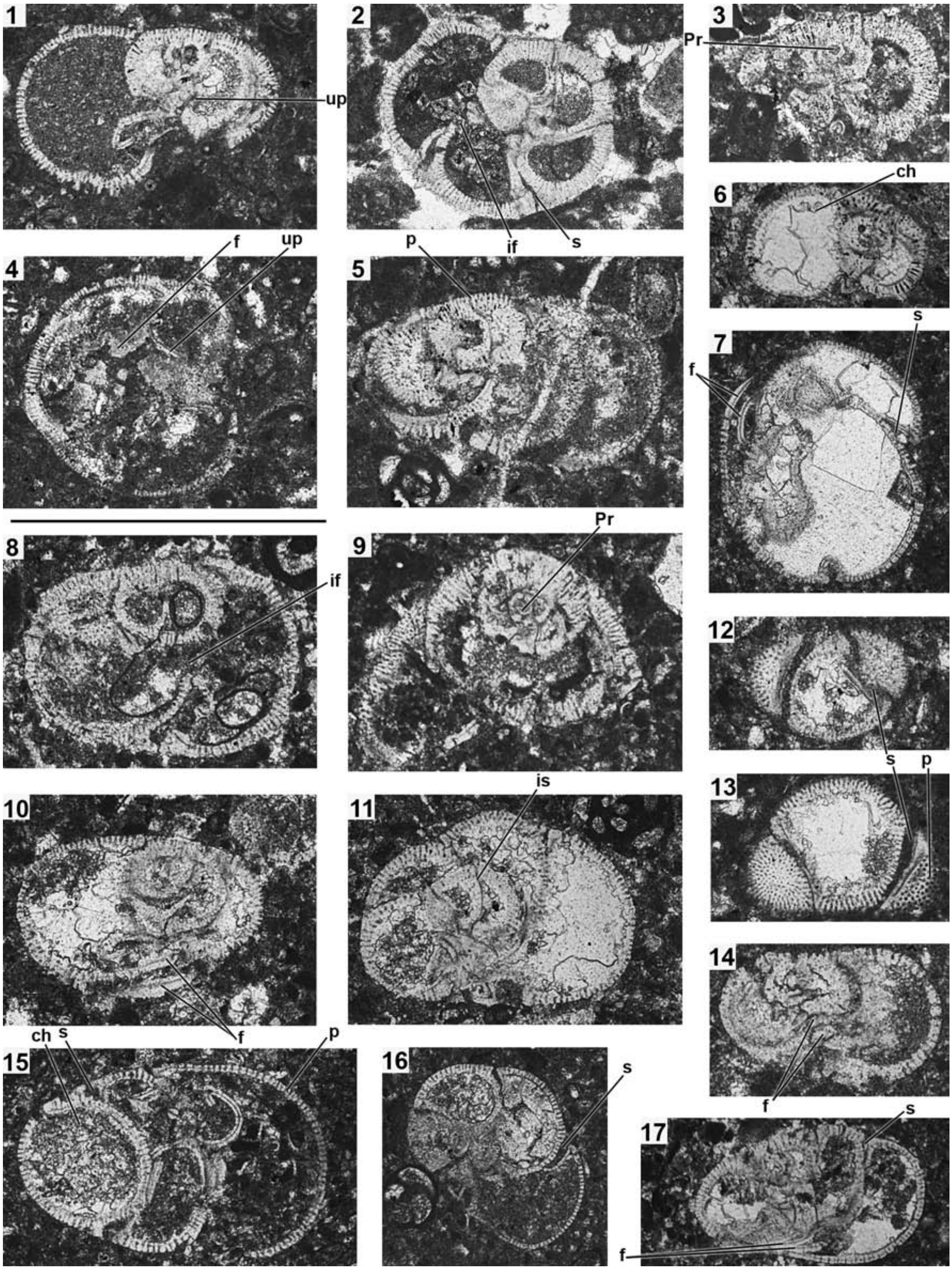

FIGURE 6. *Suturina globosa* n. gen, n. sp. Scale bar 1 mm for all specimens. 1, 3-6, 8, 9, 17 from Coscoll section (Marginal Mountains); 2 from Montroig section (Marginal Mountains); 7, 13, 15,16 from Canal de l'Embut (Montsec Mountains); 10-12, 14 from Cabana del Gabrieló (Montsec Mountains). For the Montsec Mountains see the field and stratigraphic position in Villalonga (2009). 1 Holotype. Axial section (PUAB 82504 LP01.01). 2 Transversal section, note chamber sutures (PUAB 82505 LP01.01). 3 Axial section showing the first two whorls (PUAB 82506 LP01.01). 4 Tangential Transversal section showing the ventral side with folia and umbilical plates (PUAB 82504 LP01.02). 5 Oblique section with respect to the axial section (PUAB 82504 LP01.03). 6 Close to the axial section (PUAB 82507 LP01.01). 7 Tangential section showing folia and chamber sutures (PUAB 82508 LP01.01). 8 Subaxial section

(PUAB 82509 LP01.01). 9 Centered oblique section (PUAB 82510 LP01.01). 10, 11 Oblique sections (PUAB 82511 LP01.02 and LP02.01 respectively). 12, 13 Tangential sections showing chamber sutures and pores (PUAB 82511 LP01.01 and PUAB 82512 LP01.01). 14 Close to the axial section, folia are visible occupying the umbilicus (PUAB 82511 LP01.03). 15, 17 Tangential sections showing chamber sutures and folia (PUAB 82508 LP01.02 and PUAB 82510 LP01.02). 16 Transversal slightly oblique section (PUAB 82508 LP01.03). Pr: proloculus; f: folium; if: intercameral foramina; s: chamber suture; is: intraseptal canal; p: pore; ch: chamber; up: umbilical plate

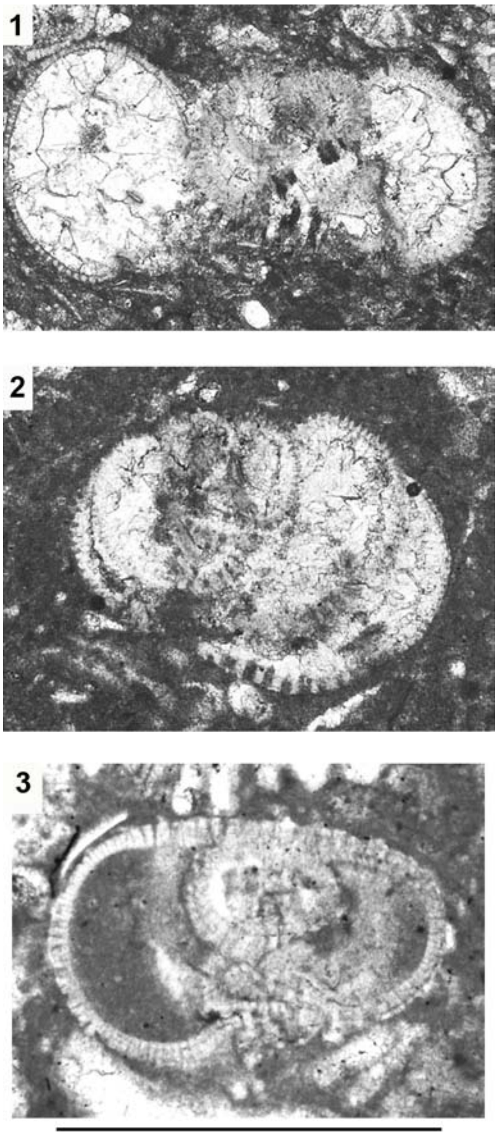

FIGURE 7. *Suturina* cf. *globosa* from Tarbur Fm, Iran. Scale bar 1 mm for all specimens. 1 Oblique close to the axial section, note the big chambers and the incised umbilicus. 2 Oblique section showing the incised umbilicus. 3 Close to the axial section.

Chapter 6

RESULTS AND DISCUSSIONS

6.1 Middle Cretaceous Global Community Maturation Cycle

New studies on LBF carried out in the present thesis provide new insights into thesy tematic classification and the biostratigraphic and palaeogeographic distributions of the studied taxa.

The stratigraphical distribution of the Middle Cretaceous GCMC Foraminifera in the Iberian Ranges (western Tethyan palaeobioprovince) and Zagros Mountains (Middle East area) suggests that the representatives (at a generic level) of the soritoidean Pseudorhapydioninae subfamily (described by Consorti et al., 2016, – paper 3 of this thesis) are widely distributed within the Tethyan palaeobioprovince. However, the LBF diversity increases from the west to the central and eastern Tethyan areas with the genus *Decastroia* and the family Myriastilidae (Piuz et al., 2014; Vicedo and Piuz, 2016). *Pseudorhapydionina* and *Pseudorhipydionina* are ”cosmopolitan” in the Tethyan palaeobioprovince, *Praetaberina* (ex “*Taberina*”) is known in Southern Italy and the Middle East (it is absent in the Iberian Ranges), whereas *Edomia* and *Cycledomia* seem to be restricted to the Middle East.

Besides the soritoideans, the earliest and simplest *Rotorbinella mesogeensis* Tronchetti and *Pararotalia boixae* Piuz and Meister (Rotaloidea) are widely distributed extending far from the Pyrenean and Tethyan palaeobioprovinces (they have been found in America, Caribbean palaeobioprovince, Navarro-Ramirez et al. in press).

The combined biostratigraphy and chemostratigraphy in the Chenareh section (paper in prep) support the evidence that all the K-strategists LBF from the Middle Cretaceous GCMC disappear before the CTB event as it occurs in other Tethyan and Pyrenean localities (Caus et al., 1993, 1997; Calonge et al., 2002; Hart et al., 2005; Parente et al., 2008), contradicting the Turonian age suggested by, for example, Razin et al. (2010) and Al-Dulaimy and Al-Sheikhly (2013).

The abundant specimens of the so-called “*Taberina*” *bingistani* Henson found in the Chenareh gorge section (Lurestan) and from other Iranian localities including its locality type has allowed re-study of the architecture of this controversial species (it was ascribed to the American Palaeogene genus *Taberina* Keijzer by Henson, but this has been widely questioned (e.g., Wittaker et al., 1998; Borghi and Pignatti, 2006; Hottinger, 2007) Wittaker et al. (1998) attributed Henson's species to the genus *Pseudorhapydionina*. The result in this thesis was the description of the new genus *Praetaberina*. Re-study of the specimens identified by Borghi and Pignatti, (2006) as "*Taberina*" *bingistani* in the Southern Italy (Polignano di Mare, Puglia) has facilitated description of the new species *Praetaberina* (*P. apula*) from Central Tethys.

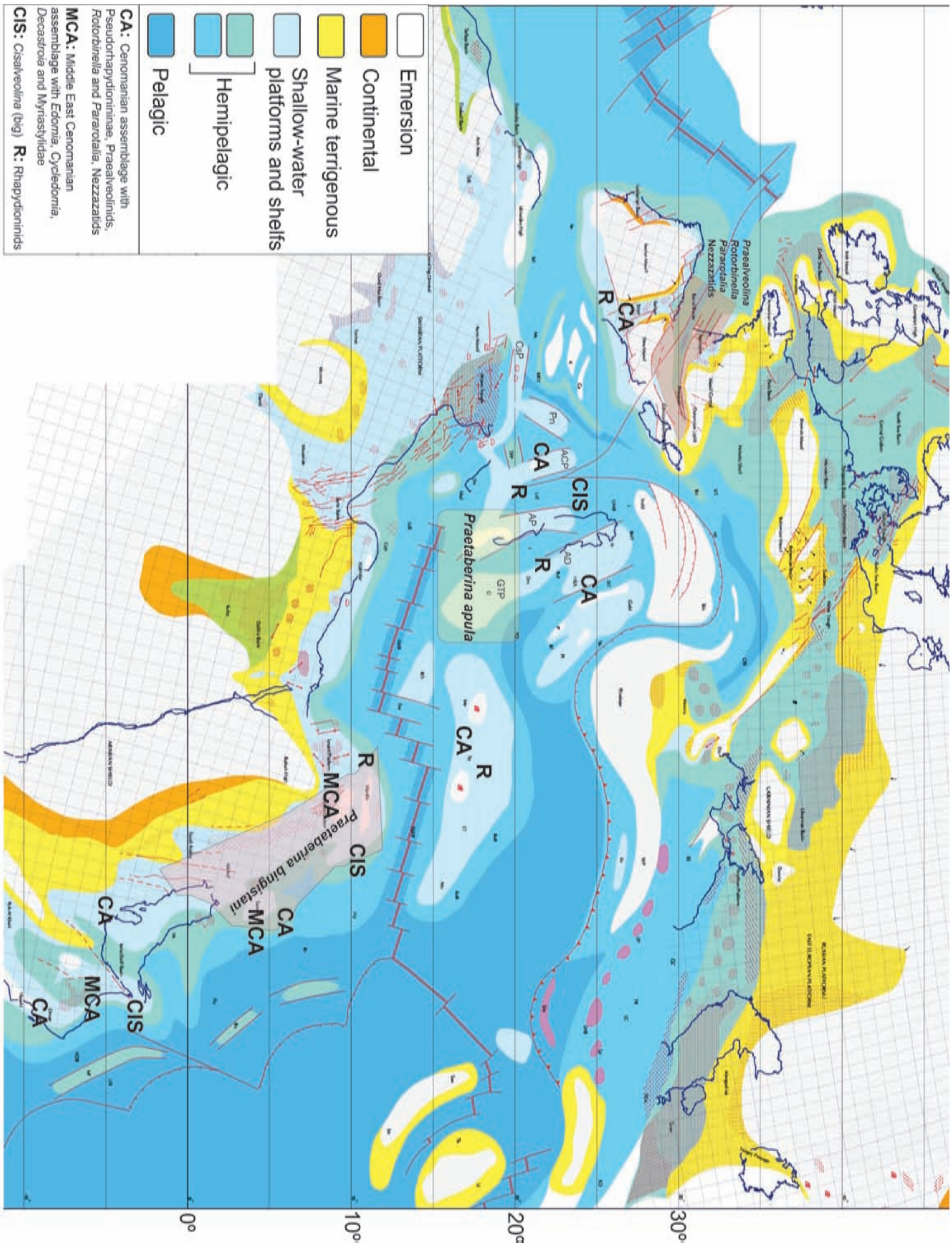

Fig. 9 - Cenomanian palaeogeography of Tethyan and Pyrenean areas (modified from Philip and Floquet, 2000 after Zarcone et al., 2010) with the distribution of the main genera and LBF associations discussed in this thesis.

6.2 Late Cretaceous Global Community Maturation Cycle

After the extinction of the CTB, the Turonian–early Coniacian shallow platform facies was rarely preserved across Tethys (there is a predominance of deep-water facies with pelagic organisms). In the few areas where shallow-water sedimentation is nearly continuous throughout the CTB, foraminiferal assemblages consists of small and simple taxa, including some survivals from the Middle Cretaceous GCMC and newcomers from the Late Cretaceous GCMC (Arriaga et al., 2016), but the larger morphotypes are still not present.

During the Late Coniacian a great development of the new structurally complex porcelaneous groups (alveolinoideans, fabularids, meandropsinids and cyclic soritoideans) and the first diversification of rotaloideans took place (Caus et al., 2010). However, timing and modality of diversification during the Late Cretaceous GCMC and synchronism of species disitributions between the two adjoining paleobioprovinces (Pyrenean and Tethyan), even in the occurence of endemic taxa, remain still unresolved.

An exhaustive study of the literature on rotaloidean Foraminifera in both palaeobioprovinces (Pyrenean and Tethyan) and new fieldwork carried out in the Central and Southern Apennines and the Pyrenees, have led to a significant advance in the knowledge of this important and complex group of LBF. In the Tethyan palaeobioprovince, one new species of the genus *Rotorbinella*, *R. lepina*, and two species of the genus *Rotalispira*, *R. vitigliana* and *R. maxima*, are described. This completes the known inventory of the Central Apennines and Southern Italy rotaloideans started by Torre (1966) with *Rotorbinella* (now *Rotalispira*) *scarsellai* and *Stensioeina surrentina*. Re-study of *S. surrentina* indicates that the specimens attributed to this taxa possess folia, foliar piles and umbilical plates, characteristics typical of the Rotaliidae (probably Lochartiinae) and do not belong to the genus *Stensioeina* (Gavellinellidae) which lack an umbilical plate and a complex canal system (see for details the revision of the genus *Stensioeina* by Dubika and Peryt, 2014). Two new taxa from the Pararotaliidae have also been described from Italy: *Pilatorotalia pignattii* and *Neorotalia*? *cretacea*. This last taxon probably should be placed in a new genus, but the material at our disposal is not sufficient for an accurate description. The age of the beds containing these new rotaloideans is constrained by means of Sr-isotope stratigraphy as Late Santonian? to Middle Campanian. However, the deposits are now covered in the vicinity of Pontone (Sorrento Peninsula, type locality of *R. scarsellai* and "*Stensioeina*" *surrentina*) and may be older than the type localities of the new taxa. In this area, the first post-CTB *Rotalispira scarsellai* appears in the Late Turonian (Frijia et al., 2015), but large morphotypes such as *R. maxima* appear only in the Early Campanian.

In the Pyrenean palaeobioprovince, the diversification of rotaloideans started during late Turonian–early Coniacian with *Rotorbinella campaniola* Boix et al., 2009, and reached maximum diversity near the Coniacian–Santonian boundary with the appearance of very large morphotypes (*Pyrenerotalia*, *Iberorotalia*, and *Orbitokathina*) interpreted as k-strategists (Boix et al., 2011).

In the Pyrenean palaeobioprovince the works of Boix et al. (2009) and Villalonga (2009) have been integrated, and the result was the description of two new taxa: *Rotalispirella acuta* and *Suturina globosa* from the Campanian–lowermost Maastrichtian. The age of the new rotaliids are constrained by means of strontium isotope stratigraphy. The genus *Suturina* is not restricted to the Pyrenean palaeobioprovince, it has been observed in the Maastricthian of Iran (Tarbur Formation; Schlaginweit and Rashidi, 2016)

In Middle East the Coniacian–Campanian is poorly characterized and contains few data on rotaloidean distribution. However, the rotaliid *Rotalia skourensis* (a taxon described from the Palaeocene) is commonly mentioned in the local literature (e.g. Afghah and Yaghmour, 2014; Omidvar et al., 2014). From re-examination of good photographs of specimens from the Middle East (e.g. Omidvar et al., 2014), we realized that the illustrated morphotypes do not have the characteristics of Pfender's species; therefore, application of this name may lead to biostratigraphic and paleogeographyc mistakes. It is probable that a true *Rotorbinella* is present among the different lamellar forms in the Upper Cretaceous of Iran, and its taxonomic attribution should be studied in the future.

Finally, new mapping and detailed stratigraphic work in the Pyrenees furnished abundant specimens of a praerhapydioninid morphotype previously cited by Bilotte (1984) and Boix (2004). The study attributes this morphotype to a new species of *Pseudorhapydionina*. The description of this new taxon suggests that this genus survived across the CTB event.

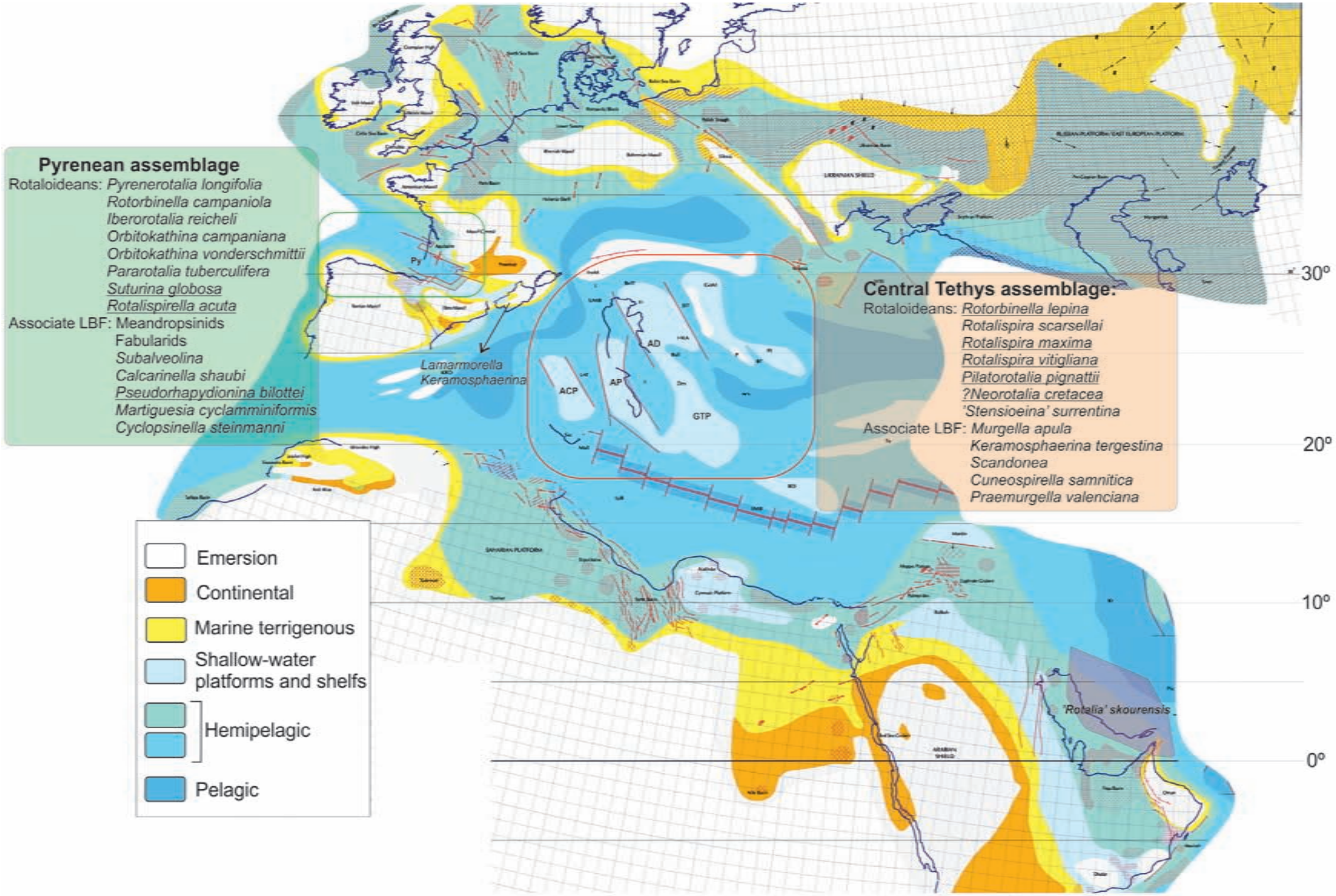

Fig. 10 - Campanian palaeogeography of Tethyan and Pyrenean areas (modified after Philip and Floquet, 2000). Rotaloideans and associate fauna for each palaeobioprovince are shown. Newly described taxa are underlined.

Chapter 7

CONCLUSIONS

A new genus, *Praetaberina* (type species *Taberina bingistani* Henson, 1948) from the Cenomanian (Middle Cretaceous GCMC) of Middle East and Central Tethys has been described. At present it includes *P. bingistani* and *P. apula*.

The Praerhapydionininae Hamaoui and Fourcade, 1973, has been elevated to the rank of family, and a new subfamily Pseudorhapydioninae has been erected to group all the Cretaceous soritoideans. With the description of *Pseudorhapydionina bilottei* from the Santonian of the Pyrenees, the range of this subfamily is, at least, latest Albian to earliest Santonian.

The Meandropsinidae Henson, 1948, has been removed from the Superfamily Soritoidea, and transferred to Ophtalmidioidea sensu Haynes, 1981. However, *Broeckina* Munier-Chalmas and its allies remain in the Superfamily Soritoidea.

Five new rotaloidean taxa have been described from the early and middle Campanian of the Central Apennines and southern Italy. *Rotorbinella lepina*, *Rotalispira vitigliana* and *R. maxima* are included in the Rotaliidae (Rotaliinae and Lockhartiinae). *Pilatorotalia pignattii* and *Neorotalia*? *cretacea* are included in the Pararotaliidae. The re-studied architecture of "*Stensioeina*" *surrentina* Torre suggests that it should be removed from *Stensioina*.

The description of *Rotalispirella acuta* and *Suturina globosa* included in the Rotaliidae (Lockhartiinae and Rotaliinae?, respectively) complete the inventory of the Pyreneean rotaloideans of the Late Cretaceous GCMC.

The presence of *Rotalia skourensis* in the Upper Cretaceous deposits of the Middle East is probably a misidentification.

The extreme k-strategist Larger Benthic Foraminifera from the Middle Cretaceous GCM Cycle were wiped out near the end of Cenomanian in both the Pyrenean and Tethyan palaeobioprovinces. But the smaller, simpler, and more cosmopolitan taxa of the same taxonomic groups, probably r-strategists, escaped the extinction. Examples include the soritoidean *Pseudorhapydionina* re-appearing in the Pyrenean palaeobioprovince (acting as a refuge during? and/or after the CTB) during the early Santonian. The rotaloidean *Rotorbinella* and *Pararotalia* represent the roots of the rotaliids and pararotaliids, respectively.

The first rotaloidean after the CTB event appear in both paleobioprovinces at the same time (late Turonian). Their diversification in the Pyrenean palaeobioprovince took place clearly during the late Coniacian–early Santonian, while in the Tethyan palaeobioprovince it seems this took place a little later, during the Santonian?–early Campanian. However, this could be biased due to facies differences between the areas: carbonate with terrigenous influx in the Pyrenees and pure carbonates in the Central Apennines and southern Italy (Puglia region).

The distribution of soritoideans and associated fauna suggests that the differentiation between the Pyrenean and Tethyan assemblages started during the Middle Cretaceous GCMC and increased during the Late Cretaceous GCMC by in addition to the known endemism among the porcelaneous Foraminifera, increasing endemism among the lamellar-perforate rotaloideans. Each paleobioprovince studied here is typified by a peculiar rotaloidean assemblage that suggests significant ecological differences existed between the two domains. Moreover, according to the data at our deposition, the Pyrenean palaeobioprovince represented a hot spot in LBF diversity during the Late Cretaceous GCMC.

Chapter 8

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Sempervisa Fault
Lupone Mt.
1378
Norma
Valvisciolo
Abbey
Sermoneta
Acquapuzza Mt.
612
Crocemoschitto
Lepini sector
S
Sempervisa subunit
Montelanico
LK
Sempervisa Mt.
1536
Carpineto
Romano
UK
Malaina Mt.
1488
Ermo Mt.
1297
Morolo
610±1
T
Sezze
Sempervisa Fault
J
Roccagorga
LK
Maenza
C
Priverno
Amaseno Va
Fosso di
Monte Acu
Caccu